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The purpose of this research effort was to develop an EEG Artifact Correction Device. This consisted of refining an existing mathematical model and implementing this algorithym on a microprocessor based, battery operated, multichannel unit that would fit in a flight suit pocket. From a scientific point of view, this project was a great success in that the mathematical technique was extended to handle blink artifacts in a non-arbitrary biophysically based manner. From an engineering point of view, the project was not a great success in that technological limitations (computing speed of CMOS processors) prevented the microprocessor from correcting more than one EEG channel in nearly real-time.

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FOREWORD

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INTRODUCTION

Nature of the Problem. Contamination of the observed electroencephalogram (EEG) by physiological artifacts such as eye movements and blinks (electrooculogram, or EOG) is a classical problem in electrophysiological studies. EOG artifacts are a major impediment in the recording and analysis of the EEG; the problem was first reported as early as 1941 and reports and attempted solutions continue to be published as recently as this year. The EEG (both steady state and evoked potential) is an important tool in the diagnosis of neurological dysfunction, such as epilepsy, cerebrovascular trauma and brain tumor, as well as in sleep studies and determining workload, mental state, and limitations of sensory information processing. Our approach uses a direct interrogation (signal injection) technique which is substantially different from the *a posteriori* techniques published by others. Direct interrogation permits on-line, virtually real time correction of eye movement artifacts on the observed EEG. We conducted a research program to add the capability of blink artifact removal to our current artifact rejection technique and implement this in a hardware device. The capability of completely correcting the EEG for EOG artifacts offers a number of significant benefits. It simplifies the acquisition and analysis of the steady state EEG and evoked potentials (EP) in clinical studies. In addition, it simplifies the development of algorithms for machine analysis of the EEG and EP; such analysis has been thwarted by the presence of EOG artifacts.

Background. A biological signal is propagated from its site of origin to a site of measurement through a medium that can, in principle, be described by a transfer function. A transfer function is merely a mathematical construct describing the relationship between the "input" and the "output" of the medium. This description can be accomplished equivalently in the time domain or, after Fourier transformation, in the frequency domain. Theoretically, the transfer function can be completely determined by measuring the response of the medium to a unit impulse; the unit impulse response is the inverse transform of the transfer function. Convolving the unit impulse response with any input always yields the output (Van Valkenburg, 1964).

It is important to note that unique transfer functions can only be defined for linear systems. All naturally-occurring systems are, in the final theoretical analysis, distributed-parameter, non-stationary, quantized, stochastic, nonlinear systems. However, it has been repeatedly proven that modelling naturally-occurring systems as nearly lumped-parameter, stationary, continuous, deterministic, linear systems can yield practically useful results (Riggs, 1970).

Observed biological signals, such as EEG, are composites of the signal of interest and other unwanted, but nevertheless, real and physiological signals. These unwanted signals are traditionally termed "artifacts". In theory, there are three ways of eliminating unwanted signals - prevention, traditional filtering, and filtering after estimation of the transfer function.

Prevention is possible for many, but not all, unwanted signals. Technical artifacts, such as 60 Hz "hum" and electrochemical effects at the electrode - tissue interface, are preventable. Certainly, artifact prevention is the ideal. However, physiological artifacts are not preventable; it is clearly "undesirable" to prevent eye movements in a visual tracking task OR to stop the maternal heart during an attempt to obtain the fetal ECG!

Traditional filtering is useful for many, but not all, unwanted signals. When there is good frequency separation between the signal of interest and the unwanted signals, filters such as Butterworth, Tschebychev, Bessel, and Cauer are useful. However, in the absence of good frequency separation (or when the bandwidth of the signal of interest overlaps the bandwidth of the unwanted signals), traditional filtering results in loss of data and signal distortion. Steep roll-off of these filters (higher order forms) results in significant phase distortion, which is often overlooked in visual analysis (Johnson et al, 1979). Often, EEG data which is deemed contaminated based on some subjective or pre-programmed criterion is simply rejected (Gratton et al, 1983) or masked (Barlow, 1985).

The problem of determining the state of a system from noisy measurements is called estimation (or filtering). With a state-space approach, the dynamical system is modeled by a finite-dimensional Markov process; the conditional probability density function of the state embodies all the information, which is available from the measurements (Jazwinski, 1970). All estimates of the state can be constructed from the density function, allowing formulation of linear and nonlinear filters and predictors. Removal of eye movement "artifacts" from observed EEG measurements is an example of such a problem. This is not merely a problem of theoretical interest; eye movements and eye blinks are a permanent source of serious unwanted signals in the measurement and analysis of the electroencephalogram (Lyman, 1941; Case, 1959; Corby & Kopell, 1972; Girton & Kamiya, 1973; Matsuo et al, 1975; Gevins et al, 1977; Whitton et al, 1978; Barlow & Remond, 1981; Verleger et al, 1982; Gratton et al, 1983; Fortgens & De Bruin, 1983; Woestenburg et al 1983; Elbert et al, 1985) and are especially troublesome in event-related brain potential measurements (e.g. CNV and P300) (Hillyard & Galambos, 1970; Wasman et al, 1970; Girton & Kamiya, 1973).

Before we ask the question "What is the transfer function which describes the coupling of the EOG to the observed EEG?", let us first review the biophysics underlying the process.

In electrodynamic terms, the eye can be modeled as a dipole (Mowrer et al, 1935; Barry & Jones, 1965). In this representation, the corneo-retinal potential difference is the result of charge separation, with the corneal aspect being positive and the retinal aspect being negative. The corneo-retinal potential is known to vary considerably between individuals (Shackel, 1967) as well as within individuals as a function of illumination (Rubin & Walls, 1969) and time (Shackel & Davis, 1960). It is further assumed (Fortgens and De Bruin, 1983; Elbert et al, 1985) that under normal conditions both eyes move conjugately. The motion of these linked dipoles creates potentials, which are observable at distant EEG recording sites. In addition to the potentials created by this dipole motion, potentials are also generated by the eyelid, acting like a sliding electrode, picking up positive potential moving across the positively charged corneal surface (Matsuo et al, 1975). The resultant change in charge distribution caused by closure of the eyelid can also be described by a change in dipole moment. Thus, the EOG can be described as an electrical potential resulting from a change in ocular dipole moment (Girton & Kamiya, 1973; Elbert et al, 1985).

The EOG potential is propagated through the medium to sites all over the body; this includes the head, which may be modeled as a four layer sphere of different conductivities (Cuffin & Cohen, 1979). The relationship between the EOG potential (measured, say, near its source) and the propagated EOG potential, at some distant site, is completely described by the transfer function of the medium (assumed linear). Numerous workers have attempted to exploit this relationship in order to remove the unwanted EOG from the observed EEG.

In its simplest form, the transfer function might be assumed to be constant and unity. However, if we merely subtract the measured EOG from an EEG measured at distant scalp sites, it is obvious that this "correction" will yield an erroneous estimate of the real EEG (Gratton et al, 1983). The transfer function could be assumed to be constant, but not unity (Barlow & Remond, 1981); however, this would not take into consideration the known dependence on the distance to the EEG electrode site from the eye (Girton & Kamiya, 1973). The transfer function could be assumed to be distance dependent; however, this does not take into consideration the known frequency and phase angle dependence of propagated volume conductor potentials (Gevins et al, 1977; Whitton et al, 1978; Woestenburg et al, 1983; Elbert et al, 1985).

From a theoretical point of view, the transfer function describing the propagation of the EOG potential (v_i [t]) through the medium to the distant recording site (v_o [t]), is a function $h[t]=h[d,A,f,\phi,t]$, such that:

$$v_o[t] = \int v_i[\mu]\, h[t-\mu]\, d\mu$$

where:

v_i = input potential
v_o = output potential
d = distance
A = amplitude
f = frequency
ϕ = phase angle
t = time

From a practical point of view, distance dependence of the transfer function can be ignored for specific, fixed electrode sites (such as in a single recording session). Frequency dependence (Gevins et al, 1977; Whitton et al, 1978; Elbert et al, 1985) and phase angle dependence (Whitton et al, 1978; Woestenburg et al, 1983) **cannot** be ignored. We can find no evidence in the literature for amplitude dependence; yet, this does not mean that it can be arbitrarily ignored without investigation. Finally, time dependence of the transfer function should not be ignored (except possibly in very short duration recording sessions), since it is a fundamental premise that biological systems change with time. An intuitive illustration of this might be the temporally-dependent impedance changes resulting from perspiration.

An analysis of the published literature clearly indicates that thinking in this area has been slowly evolving to the aforementioned full theoretical form of the transfer function and the parameters it depends upon. In fact, based on the 1985 work of Elbert et al, it appears that direct interrogation (as described later in this proposal) is the next logical area of investigation for the removal of the EOG from the EEG.

Numerous attempts have been made to estimate the transfer functions of unwanted biological signals. Bergveld & Meijer (1981) have reported a technique for removing the maternal ECG from abdominal electrocardiograms, in order to obtain a fetal ECG as well as a technique for determining the ideal electrode position (Meijer & Bergveld, 1981). They postulate a transfer function composed of the linear combination of three independent observation sites and attempt to estimate the coefficients of this linear combination. Johnson et al (1979) have reported a technique for removal of muscle artifact from the electroencephalogram. They formulate a nonlinear estimator (filter) based on an a priori model of the EEG (represented as the superposition of four lightly damped oscillators, operating in the alpha, beta, theta, and delta bands, driven by independent white Gaussian noises) and an a priori model of the muscle artifact (represented by the superposition of "action potentials" of three different durations generated as impulse responses of three linear systems driven by independent Poisson processes). Techniques for removing the EOG "artifact" from the EEG have been reported by Verleger et al (1982), Gratton et al (1983), Woestenburg et al (1983), and Elbert et al (1985).

Verleger et al report "completely correcting for blink effects", but only partial correction of eye movement artifact; this is in contrast to Weerts & Lang (1973) who "presumably removed the eye movement effect correctly, but overcompensated for the blink effect" (Verleger et al, 1982). They use a regression approach consisting of:

a. identifying maximum variance EOG segments;
b. estimating a linear regression coefficient;
c. estimating a general transmission rate;
d. correcting the EOG for DC bias; and
e. subtracting the weighted EOG from the observed EEG.

Gratton et al (1983) use a somewhat different approach. Their procedure consists of:

a. estimating correction factors derived from EOG and EEG data obtained during, rather than before, the experiment;
b. estimating separate correction factors for blinks and eye movements;
c. removing event-related EOG and EEG activity from the data; and
d. subtracting the weighted EOG from the observed EEG.

They state that their approach has six clear advantages: it distinguishes between blink and eye movement artifact; it provides corrections that are insensitive to stimulus-locked activity; it retains all data for use in subsequent analyses; it does not require special data collection; the subjects need not control or minimize eye movements; and, the estimate is based on a large sample, rather than a few data obtained from a few prescribed eye movements. They also properly point out that "noise" in the measured EOG may significantly alter the magnitude of the estimated correction factor.

Woestenburg et al (1983) report a technique for removing the eye movement artifact from the EEG by regression analysis in the frequency domain. They explicitly recognize and demonstrate that the transfer of eye movement activity to EEG can have frequency dependent amplitude and phase characteristics and they attempt to determine the transfer function. They assume that the medium is passive and constant and that there is no linear correlation between EOG and EEG activity. Furthermore, they state that "a successful method for removing the EOG artifact from the EEG should be able to handle the following phenomena:

a. Transfer from EOG on EEG is frequency dependent. Some frequencies may be attenuated more than other frequencies.
b. The EOG artifact as measured at the scalp can be distorted by phase-shifts.
c. Both vertical and horizontal eye movements may contribute to the artifact."

Woestenburg et al (1983) applied their technique to simulated data as well as to real data. The principal limitation of their technique is that it is an *a posteriori* approach typically requiring two blocks of 36 complex visual stimulus presentations and about one hour of computer time for data analysis.

Elbert et al (1985) use a biophysical approach to the theoretical formulation of the electrodynamic equations, which allow a complete description of the ocular influence in the EEG. They separate the transfer function, describing the ocular influence in the EEG, into vertical, lateral, and radial components and attempt to identify (but do not adequately support) the minimum necessary and sufficient EOG electrodes and their anatomical positions. Elbert et al explicitly recognize the frequency dependence of the transfer function; they report the form of the vertical component ($g[\omega,C_z]$) as a function of radial frequency ($\omega = 2\pi f$) as measured at the C_z. They both report theoretical and empirical forms. There are two empirical forms reported. One form, attributed to Gasser et al, is derived from naturally occurring ocular artifacts. The other form was derived following application of an (unspecified) artificial drive signal to the EOG electrodes.

The application of this artificial drive signal, by Elbert et al, forms the published "springboard" of our research efforts. The artificial drive signal, applied to the EOG electrodes, is an example of direct interrogation of the biological system under consideration. In keeping with the theoretical approach to determining the transfer function, it allows us to apply a "unit impulse", so as to completely describe the real transfer function. Judicious selection of an externally applied drive signal, when properly utilized, can be a safe, effective, and noninvasive means of determining the transfer function of the ocular influence on the EEG. An artificial drive signal has already been applied by Elbert et al (1985) and by us (unpublished, 1985 and Falk et al, 1987). Sullivan (1965) reported use of a 40 KHz drive signal for measuring impedance in order to determine the direction of the ocular dipole.

All the previously cited literature (with the exception of Elbert et al) attempt to determine the transfer function (correction factor, weighting factor, regression coefficient, etc.) through the use of naturally occurring ocular motions. Since there are, potentially, an infinite number of different ocular motions, selection of specific motions (Weerts & Lang, 1973; Verleger et al, 1982; Fortgens & De Bruin, 1983) obviously lacks generality and completeness. The work of Woestenburg et al (1983), and then Gratton et al (1983), begins to circumvent this problem by basing the estimate on a large sample, rather than a few data obtained from a few prescribed eye movements. But even this approach does not fully address the problem. Our approach is to apply an external drive signal which describes all possible ocular motions; these ocular motions are merely an electrical signature composed of particular amplitudes at particular frequencies with particular phase relations. In fact, because the biopotentials generated by ocular motion are not unbounded, the EOG does NOT contain all possible amplitudes and frequencies; the EOG is constrained to frequencies below, say for example, 30 Hz and to amplitudes below, say for example, 5 mV. Therefore, practically, the "unit impulse" required to theoretically determine the transfer function need not be an impulse input, $\delta(t)$; instead, it can be a relatively short time duration pulse whose frequency transform includes those frequencies of interest.

Purpose of the Present Work. The purposes of this research study were twofold: first, to refine our existing mathematical technique, and second, to implement it in a portable, battery-operated twelve channel device.

Methods of Approach - Mathematical. The mathematical technique that allows us to remove the eye movements from the on-going EEG is called the direct interrogation technique. Three basic assumptions are made in order to utilize this technique. We assume that the eye movement signal propagates only on the surface of the head to the distant EEG sites. Since the skull is approximately eighty times the resistivity of the scalp, the path of least resistance is the scalp. Depth electrode studies have been conducted and there was no evidence of EOG artifact in the EEG (Cooper, 1971). We also assume that the medium is linear (thus the theory of superposition holds) and the medium is non-dispersive (no shift in frequency). We have tested both these assumptions and we find them to be true. With this as our base, we can model this system as an input (EOG), an output (EOG artifact on the EEG), and a medium (scalp) and its transfer function.

Before we discuss the models of eye movement and eye blink, we must discuss some terminology regarding the ocular dipole. An electric *dipole* is an electric potential source arising from the separation of equal and opposite charges and resulting in an electric field whose magnitude is nonzero at all points in space except those equidistant from both charges. These equidistant points define a unique *zero-potential plane* orthogonal to the line connecting both charges. The *ocular dipole* is an electric dipole with the positive charge on the cornea and the negative charge on the retina. The *conjugate eye dipole pair* is comprised of the two linked ocular dipoles that move in parallel. The *surface image* of a dipole is that portion of the electric field residing on a surface transecting the three dimensional dipole electric field. The image of the zero-potential plane on the surface is a *zero-potential line.* The *surface image of the ocular dipole* is the image on that surface defined by the skin on the head (including the face). The zero-potential line forms an angle ϕ with the x-axis of our geometrical coordinate system. A direct interrogation stimulus dipole or "*surface stimulus dipole*" is the electric source resulting from the application of two spaced surface electrodes driven by a floating voltage source (a floating battery).

We made the following explicit assumptions: **(a)** the EOG signal reaches the EEG recording site via surface propagation (propagation by other means is negligible); **(b)** the medium is passive and constant (over relatively short time periods); **(c)** the principle of superposition holds (the system is linear or nearly linear) and a unique transfer function does exist; **(d)** the medium is non-dispersive (frequencies don't change during propagation); and **(e)** our mathematical model properly represents the electrodynamic behavior of the conjugate eye dipole pair. While further investigation is required, we presently believe that no other implicit assumptions have been made.

CORRection of the observed EEG for EOG artifacts ($^{corr}V_{EEG}[\omega]$) is accomplished in the frequency domain and is based on **(a)** measurement of the **OBS**erved EEG ($^{obs}V_{EEG}[\omega]$) and **OBS**erved EOG ($^{obs}V_{EOG}[\omega]$), **(b)** measurement of the system response to **STIM**ulation ($^{stim}V_{EEG}[\omega]$ & $^{stim}V_{EOG}[\omega]$) for direct interrogation, **(c)** a mathematical model that describes the electrodynamic behavior of the system for **T**heoretical **E**ye **M**ovements ($^{tem}V_{EEG}[\omega]$ & $^{tem}mV_{EOG}[\omega]$) and **T**heoretical **D**irect **I**nterrogation ($^{tdi}V_{EEG}[\omega]$ & $^{tdi}V_{EOG}[\omega]$), and **(d)** measurement of the **CAL**ibration of each recording channel ($^{cal}V_{EEG}[\omega]$ & $^{cal}V_{EOG}[\omega]$). The mathematical derivation is summarized here.

The formula for implementing the EEG correction, on a frequency per frequency basis, is:

$${}^{corr}V_{EEG}\,[\omega] = {}^{obs}V_{EEG}\,[\omega] - (S \times D/G)\;{}^{obs}V_{EOG}\,[\omega]$$

where:

$$S = {}^{stim}V_{EEG}\,[\omega] + {}^{stim}V_{EOG}\,[\omega] \qquad \text{(using 20 } \mu\text{A stimulus pulse)}$$

$$G = {}^{cal}V_{EEG}\,[\omega] + {}^{cal}V_{EOG}\,[\omega] \qquad \text{(using 1 mV calibration pulse)}$$

$$D = ({}^{tem}V_{EEG}\,[\omega] + {}^{tem}V_{EOG}\,[\omega]) + ({}^{tdi}V_{EEG}\,[\omega] + {}^{tdi}V_{EOG}\,[\omega])$$

S is a measure of the system response to direct interrogation and is the ratio of the signals observed at the EEG and EOG recording sites; it is the putative transfer function. G is a measure of the discrepancy between the recording channels and is the ratio of the calibration signals observed at the EEG and EOG recording sites; G would not be necessary, if and only if the recording channels were absolutely identical. D is a geometrical correction factor that interrelates the theoretical electrodynamic behavior of the (non-collocated) direct interrogation stimulus dipoles and the ocular dipoles; it is, in fact, our mathematical model. It must contain both magnitude and phase information, so it has the form:

$$D = D'e^{i\xi}$$

where D' describes the magnitude correction due to geometry and ξ describes the phase correction due to geometry. The geometrical correction factor D would not be necessary, if and only if the direct interrogation stimulus dipole exactly and completely emulated the ocular dipoles geometrically and electrodynamically.

D' was derived by obtaining the general solution of the general differential equation that describes the propagation of a potential generated by any source. The general solution was constrained to model a dipole source. Using this equation, the conjugate eye dipoles were resolved into a single equivalent theoretical source located at the origin of our selected coordinate system. Similarly, by coordinate transformation, the stimulus dipoles were converted to an equivalent theoretical source <u>also</u> located at the origin of our coordinate system. With these two source equations, the magnitude relationship of the signals expected at the EEG and EOG recording sites (as a result of eye movements versus surface dipole stimulation) was computed. This permits computation of the magnitude portion of the geometrical correction factor; it is used to correct the empirical transfer function (found by direct interrogation stimulation) for the difference in geometry between the stimulus dipoles and ocular dipoles.

Phase changes due to propagation through the medium and this information is contained in the empirical transfer function obtained by direct interrogation. Additionally, there is a relative phase shift between the EEG and EOG recording sites. It is due solely to the changing geometric orientation of the isopotential lines caused by rotation of the surface image of the ocular dipole. This information is not contained in the direct interrogation data and must be independently corrected. The equation describing the single equivalent theoretical source of the conjugate eye dipole is a function of the angle of rotation ϕ of the surface image of the ocular dipole pair. Differentiation of this equation with respect to ϕ yields an equation describing the change in potential at an EOG electrode due to a change in ϕ. When the change in potential with respect to ϕ is zero, the potential is at an extremum (maximum or minimum) and the corresponding ϕ, at a particular electrode site, can be computed. This value of ϕ is the value of the angle of rotation that creates an extremum at the particular electrode site under consideration. It will have different values for different electrode sites. The geometrically-dependent relative phase shift between an arbitrary pair of electrode sites is the difference of their corresponding ϕ's. A change in ϕ can not be determined from one EOG electrode; in general, an orthogonal pair is preferred.

Our mathematical technique can be summarized as follows. Integral to our technique are the following four (4) <u>explicit</u> assumptions:

a. the EOG artifact on the EEG is the result of an electrodynamic process, arising from the movement of the eye dipoles and from the eyelids across their surface (Elbert et al, 1985);
b. the EOG artifact reaches the EEG recording site primarily via surface propagation (propagation by other means is negligible) (Cooper et al, 1965, 1971; Cuffin and Cohen, 1979);
c. the surface propagation medium is passive, linear, and non-dispersive (over relatively short time periods); thus, a unique transfer function exists - this was shown in our feasibility demonstration; and
d. all possible eye movements and blinks are completely described by their Fourier components, and these consist of a bounded set of frequencies, amplitudes, and phases.

Therefore, EOG propagation between the site of EOG generation and the EEG electrodes can be characterized by a transfer function; the transfer function in turn can be characterized by injecting a signal at the EOG generation site and recording the resultant signal at the EEG electrodes (direct interrogation).

This method of rejecting ocular motion artifacts on the EEG recording can be mathematically expressed as:

$$EEG^{c}(t) = EEG^{o}(t) - IFT\,\{EOG^{o}(s) \times S(s) \times G(s) \times D\}$$

where:		
$EEG^{c}(t)$	=	Corrected EEG (time domain)
$EEG^{o}(t)$	=	Observed EEG (time domain)
IFT	=	Inverse Fourier Transform
$EOG^{o}(s)$	=	Observed EOG (frequency domain)
S(s)	=	Transfer function (frequency domain)
G(s)	=	Channel response correction factor (frequency domain)
D	=	Geometric correction factor

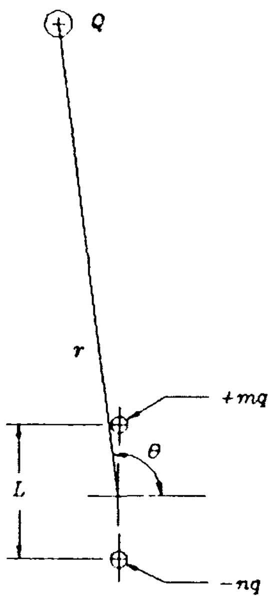
Methods of Approach - Engineering. The mathematical technique is an algorithm for removing the unwanted influence of the EOG on the observed EEG. This can be implemented in hardware by constructing a microprocessor-based device which can be programmed to execute this algorithm. Amplifiers and filters are used to condition biopotential signals which can then be digitized and processed. These processed data can be once again converted to analog signals for display and recording. The digital processing time will introduce a finite delay due to the time required for the microprocessor to execute the necessary computations. Standard engineering techniques permit implementation of the analog and digital circuitry in a form that requires minimal power, and thus can be battery operated.

BODY

Refinement of the Mathematical Technique. In this research study, we have expanded the biophysical model to include the blink. This yields a general electrodynamic model for both the source and the propagating electric field from the eye for all possible eye movements and blinks.

The Biophysical Model. The transection of the face across the three dimensional ocular dipole field (caused by the corneo-retinal potential in the eye) yields a surface image dipole propagating on the scalp. This surface image dipole can be modelled to incorporate both the eye movement and the eye blink. The eye movement produces a symmetric dipole, while the blink produces an asymmetric dipole.

General Dipole Representation. A dipole source, symmetric or asymmetric, is the superposition of two point sources separated by a distance. The point source's electric field propagates as a function of $1/r^2$. The voltage at any point is described by $V=kq/r$, where k is Boltzmann's constant, and q is the amount of charge. The surface image dipole is described here.



The figure on the left shows two point sources separated by a distance (L). The voltage (V) appearing at point Q is derived as follows.

$$V = kq\{[m/(r-\tfrac{1}{2}L\sin\theta)]+[-n/(r+\tfrac{1}{2}L\sin\theta)]\}. \quad (1)$$

Rearranging Equation 1 yields

$$V = kq\{[(m-n)r+(m+n)\tfrac{1}{2}L\sin\theta]/(r^2-\tfrac{1}{4}L^2\sin^2\theta)\} \quad (2)$$

Since r>>L, we can *simplify Equation 2:*

$$V = n[(kq/r^2)\tfrac{1}{2}L\sin\theta(\alpha+1) + (kq/r)(\alpha-1)], \quad (3)$$
$$\text{where } \alpha = m/n.$$

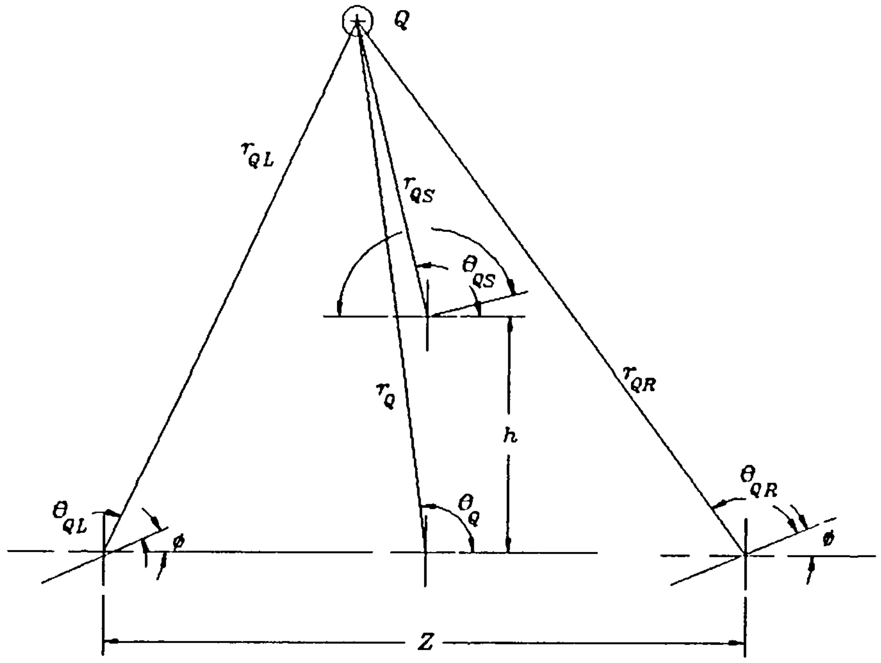
As a note, if $\alpha=1$ (eye movement) and the dipole is symmetric, Equation 3 reduces to,

$$V = (nkq/r^2)L\sin\theta = Ar^{-2}\sin\theta. \quad (4)$$
$$\text{where } A = nrqL.$$

Furthermore, it is important to note that the zero-potential line of the dipole is the x-axis when $\alpha=1$ ($\sin\theta=0$). When $\alpha\neq1$, the zero-potential line becomes a circle described by,

$$x^2 + (y+G)^2 = G^2, \quad (5)$$
$$\text{where } G=\tfrac{1}{2}L[(\alpha+1)/(\alpha-1)].$$

Selection of a Facial Coordinate System. In order to spatially represent the ocular dipoles or the stimulus dipole in planar geometry, we must select a coordinate system. This is shown in the figure below. The point, Q, in this figure represents an electrode. The subscript L is used to show reference to the left eye, the subscript R is used to reference the right eye. The electrode is a distance β_L from the left eye and β_R from the right eye. Reference to the stimulation dipole is indicated by S. Our facial coordinate system has its origin at the geometric center of the two eyes (which are separated by a distance z). The stimulus dipole is located a distance h above the origin. The electrode is a distance r from the origin of the coordinate system. The stimulation dipole lies on the y-axis as the eyes lie on the x-axis.



Spatial Resolution of the Bi-ocular Dipoles. Using our coordinate system and dipole representation described above, we will model the two ocular dipoles as one complex mathematical function based at the origin of the coordinate system.

From the law of cosines:

$$\beta_L = [r^2 + \tfrac{1}{4}Z^2 + rZ\cos\theta]^{\frac{1}{2}} \quad (6)$$

$$\beta_R = [r^2 + \tfrac{1}{4}Z^2 - rZ\cos\theta]^{\frac{1}{2}} \quad (7)$$

From the law of sines:

$$\gamma_L = -\phi + \sin^{-1}[(r/\beta_L)\sin\theta] \quad (8)$$

$$\gamma_R = \pi - \phi - \sin^{-1}[(r/\beta_R)\sin\theta] \quad (9)$$

where: ϕ = angle of the ocular dipoles (zero-potential line).

We now substitute these identities (Eqns. 6-9) into the dipole equation defined earlier (Eqn. 3) and sum the two ocular dipoles to result in one function. We obtain this, in a general form, for any electrode:

$$V = \tfrac{1}{2}(\alpha+1)A\{[\beta_L^{-2}[-(1-\gamma_L^2)^{1/2}]\sin\phi+\gamma_L\cos\phi]+[\beta_R^{-2}[(1-\gamma_R^2)^{1/2}]\sin\phi+\gamma_R\cos\phi]\}+(A/L)(\alpha-1)\{\beta_L^{-1}+\beta_R^{-1}\}, \tag{10}$$

where:

$$\beta_L = [(r)^2+(\tfrac{1}{2}Z)^2+rZ\cos\theta]^{1/2}$$
$$\beta_R = [(r)^2+(\tfrac{1}{2}Z)^2-rZ\cos\theta]^{1/2}$$
$$\gamma_L = (r/\beta_L)\sin\theta$$
$$\gamma_R = (r/\beta_R)\sin\theta$$

Spatial Representation of the Stimulus Dipoles. We can similarly describe the representation of the stimulus dipole in our new coordinate system as we have described the ocular dipoles above. Using Equation 4:

$$V = B\{\sigma^{-2}[\eta\sin\psi-(1-\eta^2)^{1/2}\cos\psi]\} \tag{11}$$

where:

$$\sigma = [r^2 + h^2 - 2rh\sin\theta]^{1/2}$$
$$\eta = (-r/\sigma)\cos\theta$$
ψ = angle of the stimulus dipole (an analog of ϕ)

Equations 10 & 11 and the associated identities are the basis of the mathematical model which will be used in the calculation of the transfer function.

Mathematical Relationship Between Resultant Ocular Dipoles & Stimulus Dipoles. We can now use our basic equations and our coordinate system to correct the putative transfer function measured by surface dipoles. The EOG artifact correction equation in the frequency domain is:

$${}^{corr}V_{EEG} = {}^{obs}V_{EEG} - {}^{obs}V_{EOG}\,[S_{EEG}/S_{EOG}]\,D \tag{12}$$

where D is the geometrical correction factor between the stimulus dipole and the ocular dipoles. S denotes the surface dipole stimulation response and ${}^{obs}V$ denotes the naturally occurring response. The subscript "EEG" and "EOG" refer to the electrode recording the response; the superscripts "corr" and "obs" refer to the corrected and observed potential, respectively.

We can obtain D by manipulation of the equations described above.

$$D = \frac{\dfrac{\{\frac{1}{2}(\alpha+1)[[\beta_L^{-2}\,[-(1-\gamma_L^2)^{1/2}]\sin\phi+\gamma_L\cos\phi]+[\beta_R^{-2}\,[(1-\gamma_R^2)^{1/2}]\sin\phi+\gamma_R\cos\phi]]+((\alpha-1)/L)[\beta_L^{-1}+\beta_R^{-1}]\}_{EEG}}{\{\frac{1}{2}(\alpha+1)[[\beta_L^{-2}\,[-(1-\gamma_L^2)^{1/2}]\sin\phi+\gamma_L\cos\phi]+[\beta_R^{-2}\,[(1-\gamma_R^2)^{1/2}]\sin\phi+\gamma_R\cos\phi]]+((\alpha-1)/L)[\beta_L^{-1}+\beta_R^{-1}]\}_{EOG}}}{\dfrac{\sigma^{-2}\,[\eta\sin\psi-(1-\eta^2)^{1/2}\cos\psi]_{EEG}}{\sigma^{-2}\,[\eta\sin\psi-(1-\eta^2)^{1/2}\cos\psi]_{EOG}}} \tag{13}$$

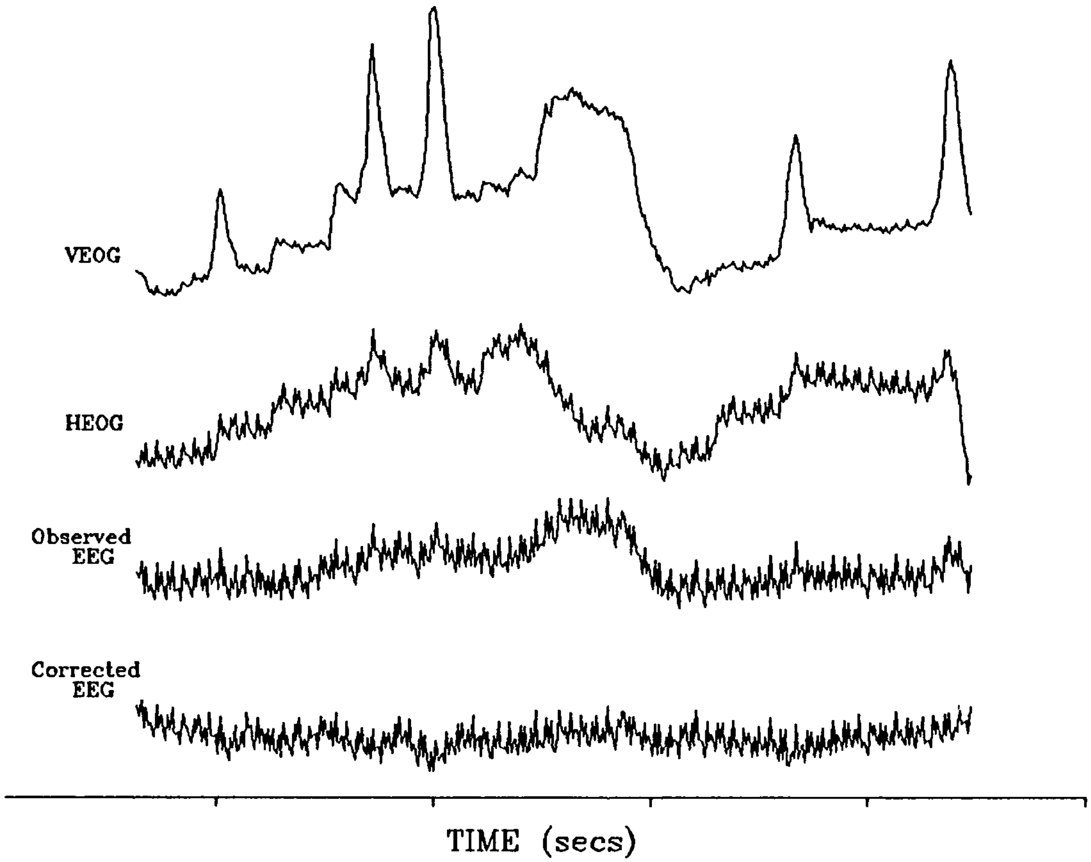
where,
$\beta_L = [(r)^2+(\frac{1}{2}Z)^2+rZ\cos\theta]^{1/2}$,
$\beta_R = [(r)^2+(\frac{1}{2}Z)^2-rZ\cos\theta]^{1/2}$,
$\gamma_L = (r/\beta_L)\sin\theta$,
$\gamma_R = (r/\beta_R)\sin\theta$,
$\sigma = [r^2 + h^2 - 2rh\sin\theta]^{1/2}$,
$\eta = (-r/\sigma)\cos\theta$,

$$\phi = \begin{cases} 0° \text{ for vertical EOG} \\ 90° \text{ for horizontal EOG} \end{cases}$$

$$\psi = \begin{cases} 0° \text{ for vertical interrogation pulse} \\ 90° \text{ for horizontal interrogation pulse} \end{cases}$$

$\alpha = m/n =$ (obtained in real time as $\mathrm{EOG}_{\mathrm{vertical}}^{\mathrm{upper}} / \mathrm{EOG}_{\mathrm{vertical}}^{\mathrm{lower}}$).

We measure z and h, as well as β_L and β_R for each electrode (EEG and EOG). We then calculate r and θ for each electrode, and then calculate γ_L, γ_R, σ, and η for each electrode. Finally, we calculate D's for each EEG/EOG electrode combination. This permits correction of the observed EEG in accordance with Equation 12. The next figure shows an example of a correction. The cross-correlation between the observed EEG and the vertical EOG was 0.75; the cross-correlation between the corrected EEG and the vertical EOG was 0.017.



Implementation of the Technique in Hardware. The implementation of the technique described above required an extremely fast microprocessor. The specification that the portable, light-weight device must fit in a flight suit pocket required a low-power CMOS microcontroller. These specifications resulted in the selection of the Intel 80C196 microcontroller. This chip contains a very fast microprocessor, an on-board analog-to-digital converter, extremely low power consumption, and an already written and tested Fast Fourier algorithm.

There were many obstacles encountered with the use of this microcontroller. There is a design flaw in the chip. Intel has since published this flaw and has an updated chip. The flaw is in the unsigned divide instruction. The result from this instruction is either the correct answer or one least significant bit away from the correct answer. This doesn't seem like a major problem on the surface, however in a thirty two bit divide algorithm, the unsigned divide is used. What intermittently occurs is an incorrect answer which is off by one least significant bit in the HIGH word; the result is that the numerical answer is off by 65,536!

Another flaw in the chip is that the on-board eighty bytes of RAM is sporadically overwritten. If variables located in the onboard RAM are forced into the external RAM space, the problem seems to disappear.

There is a flaw in the C compiler written for the 80C196. A locally defined variable is being overwritten by a subroutine containing the same, but locally defined, variable. Using identically defined but locally defined variables is standard and "legal" in C, yet this compiler does not seem to properly handle this situation.

There is another flaw in Intel's system. The in-circuit emulation system, used to develop software for the C196, defines the ROM as zero wait state memory. This causes major timing problems, because the ROM should be activated with the user programmable wait states, which can be either one, two, or three. Yet, the emulator disregards this programmable wait state number and accesses the ROM in zero wait states. Intel has been notified of this timing flaw. This undocumented discrepancy makes the software created on the emulator incompatable with the Intel target hardware that would be used in a portable device.

There also have been other general problems plaguing this effort. This microprocessor is an integer based machine. This leads to two hurdles. First, the resolution of the mathematics is truncated to digital steps and not continuous functions. The ratio of one to one half is two in the continuous world, yet the ratio of one to zero (one half is truncated to zero) is infinity in the digital world. The second hurdle is that the integer set is bounded at -32,768 to 32,767. This constraint causes the programmer to scale numbers down as they grow close to the bounds. This is a double-edged sword, since the function of scaling is division, which leads to truncation!

This constraint of integer math caused us to require the use of a host PC and to perform the calculations of the model parameters and the transfer function on the host PC (since floating point arithmetic is necessary here). This eliminates the option of continually interrogating the medium while the subject is ambulatory.

The blink component of the model, although an excellent advance in the biophysical model, added complexity to the correction technique. This complexity added a significant amount of computation time to the microprocessor based program. This result was that there was only time for one channel to be corrected with the full model.

In order to achieve this correction of one channel in the allotted (real) time, there were several "shortcuts" that were necessary. The vertical and horizontal transfer functions were reduced from an array of complex numbers (one for each frequency) to one complex number. We showed that the transfer function varied less than ten percent over the frequency spectrum. This allowed us to reduce these arrays, yet it is a practical variation from the theoretical ideal. Another shortcut was the elimination of the square root. In calculating the absolute value of the ratio of the upper VEOG to the lower VEOG, a square root was necessary. We showed that the imaginary component of the complex ratio was very close to zero, so we took the real component of the ratio instead of the absolute value.

There were many technical obstacles that complicated this research study and prevented us from correcting twelve channels of EEG for EOG artifact. We have successfully fabricated a device that will accurately correct one channel of EEG for EOG artifact. As indicated in the previous discussion, it is suceptable to sporadic failures caused by the Intel 80C196. Application specific circuits and chips can be used to implement this correction technique on multiple channels, however the power consumption will cause the battery size and weight to increase significantly. This would result in a device too large and heavy to place in a pocket or wear on the body.

CONCLUSIONS

From a scientific point of view, this project was a great success in that the mathematical technique was extended to handle blink artifacts in a non-arbitrary biophysically based manner. From an engineering point of view, the project was not a great success in that technological limitations (computing speed of CMOS processors) prevented the microprocessor from correcting more than one EEG channel in nearly real-time.

There were many technical obstacles that complicated this research study and prevented us from correcting twelve channels of EEG for EOG artifact. We have successfully fabricated a device that will correct one channel of EEG for EOG artifact. Application specific circuits and chips could be used to implement this correction technique on multiple channels, however the power consumption will cause the battery size and weight to increase significantly. This would result in a device too large and heavy to place in a pocket or wear on the body. Full implementation of a multichannel man-borne device must wait advances in computer hardware technology.

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APPENDIX

The following appendix is the operations manual for the EEG Artifact Rejection System (EARS) device.

LIST OF PERSONNEL RECEIVING PAY ON CONTRACT #DAMD17-89-C-9045

GEORGE M. SAMARAS, PhD, P.I.
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OPERATING & MAINTENANCE INSTRUCTIONS for

PROTOTYPE ELECTROENCEPHALOGRAM ARTIFACT REJECTION SYSTEM (EARS)

Prepared for:

Department of the Army
U.S. Army Medical Research Acquisition Activity
Fort Detrick, Frederick, Maryland 21701

Prepared by:

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Columbia, Maryland 21045

Contract No.: DAMD17-89-C-9045

March 1990

CONTENTS

LIST OF FIGURES

I. PREFACE

This manual contains information needed for the operation and maintenance of an experimental prototype device, which provides nearly real-time correction of artifacts on the steady state electroencephalogram (EEG). The prototype EEG Artifact Rejection System (EARS) is a battery-operated, portable device that is **designed** to operate in a variety of experimental operational settings (laboratory, simulators, and aircraft) and is intended to fit in the calf pocket of a flight suit. While the experimental device has been tested in a laboratory setting, it has **NOT** been evaluated in a simulator or on an aircraft. Furthermore, while it has been subjected to limited human testing, it is not an approved clinical device - it is an experimental prototype. The EARS device should only be used on humans under the auspices of an experimental protocol approved by a duly constituted Internal Review Board.

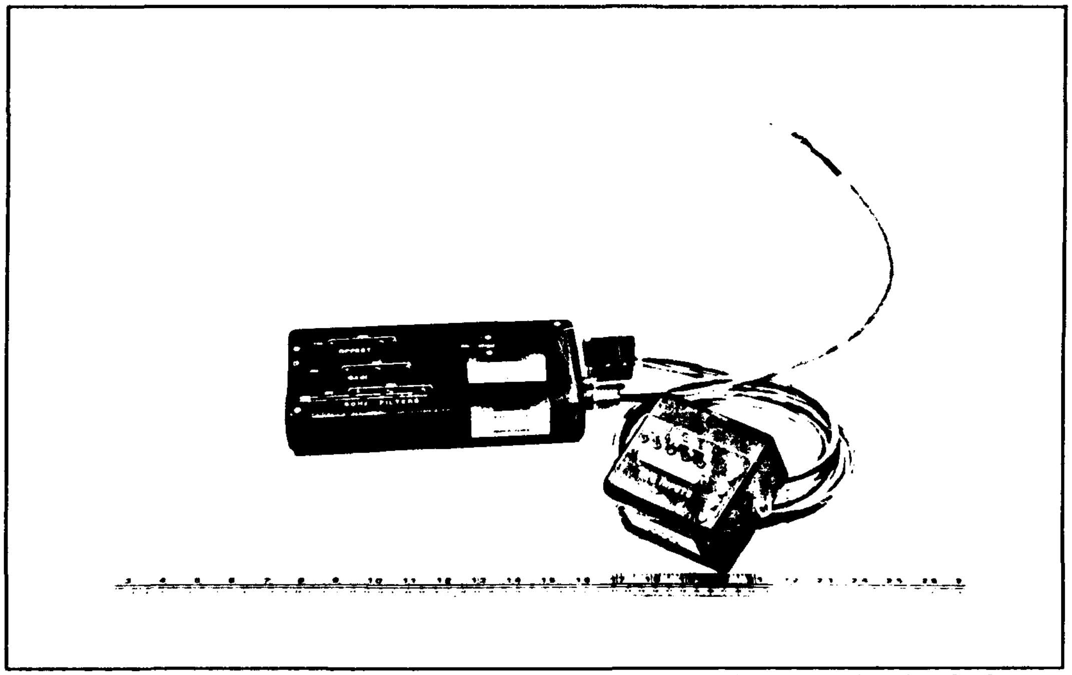


FIGURE I.1: ELECTROENCEPHALOGRAM ARTIFACT REJECTION SYSTEM

II. DESCRIPTION

The EARS device is a portable unit consisting of a processor unit (which fits in a flight suit calf pocket) and an electrode input selector unit (a "relay box", which is intended to be slung about a subject's neck, as shown in Figure II.1).

The relay box accepts a standard multipin EEG electrode input connector as well as nine (9) additional electrode connections (one pair of ear electrodes, one pair vertical stimulation electrodes, one pair horizontal stimulation electrodes, one pair vertical EOG electrodes, and one single horizontal EOG electrode). These nine electrodes and any one of the 24 EEG electrodes (see Figure IV.1) are transmitted to the processing unit via a cable using standard 25 pin D connectors.

The processing unit communicates with the relay box via its 25 pin D connector, with a host PC via its 9 pin D connector, and with an analog output signal recorder via its 9 pin round connector. The operating mode of the processing unit can be selected from a menu, displayed when the device is connected to a host computer. The processing unit operates in one of three major modes: real-time mode, interrogation mode, and correction mode. In the "real-time" mode, the unit acts as a conventional biopotential amplifier system. In the "interrogation" mode, the unit acquires EOG data and EEG data (only from the one selected channel) for use by the host PC to compute model parameters for the "correction" mode. In the "correction" mode, the unit acquires EEG and EOG data, computes the EOG contribution to the EEG data (using the model and model parameters), subtracts the EOG contribution from the EEG signal, and outputs the corrected signals with a few seconds delay.

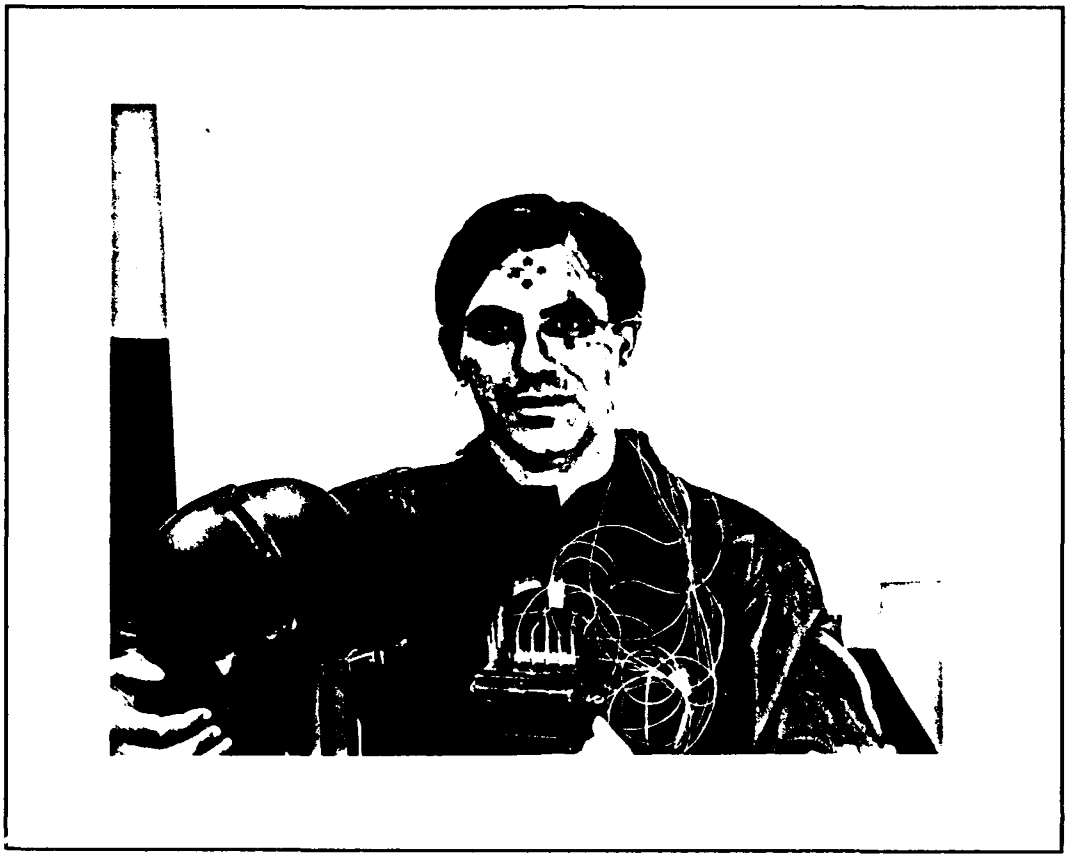


FIGURE II.1: ELECTRODE INPUT SELECTOR UNIT (RELAY BOX)

III.INSTALLATION

The hardware consists of four components. There is the EARS main processor unit, an electrode input selector unit, a interconnection cable that connects these two units, and an analog output cable. A separate RS-232 9-pin "D" communications cable must be provided for the communication with the host PC. The "relay box" has two screws on the top, that when unscrewed, allow the lid to open and the batteries to be replaced as shown in Figure III.1. Figure III.2 shows the parallel battery terminal connectors that permits replacing the batteries without interrupting operation of the unit.

Software for the host PC is contained on a 3.5" disk. One can install this software by copying the disk onto a hard disk. The PC must be an IBM PC/AT/XT with a numeric coprocessor. This is done by typing "copy a:*.*" when in the desired directory on the hard disk. The user is now ready to operate the EARS system.

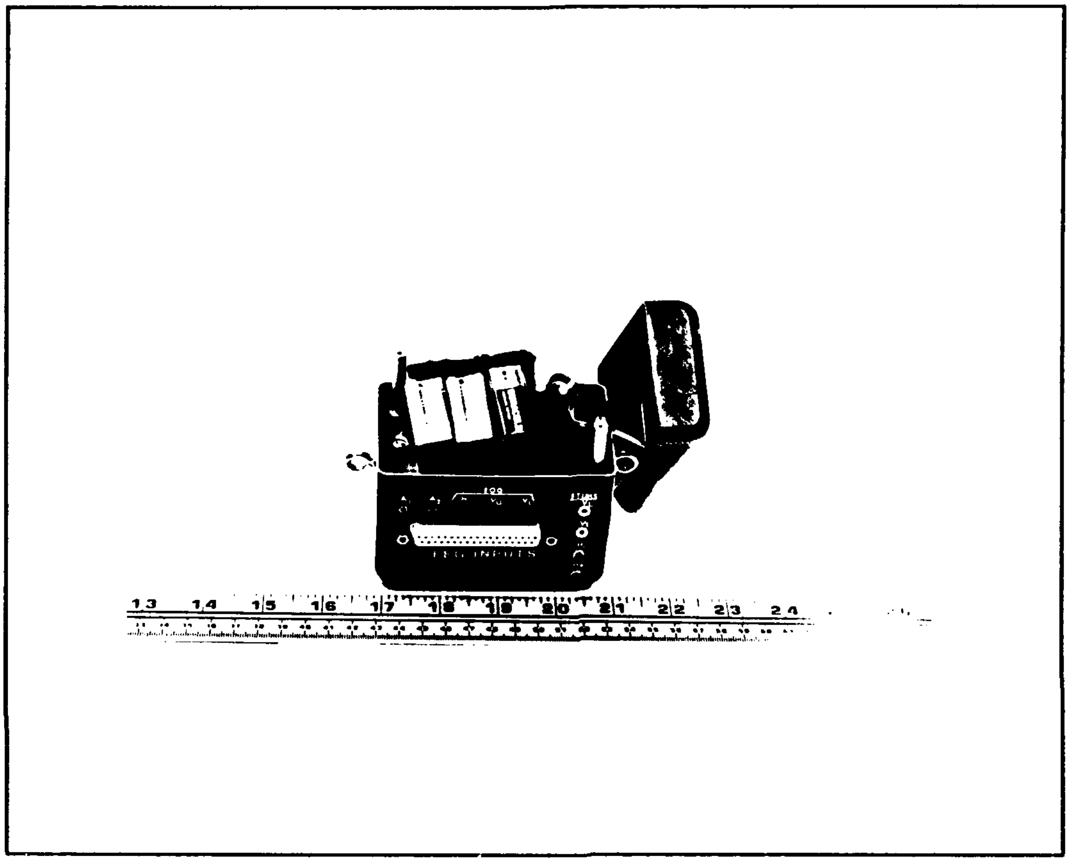


FIGURE III.1: POSITIONING OF THREE 9V BATTERIES

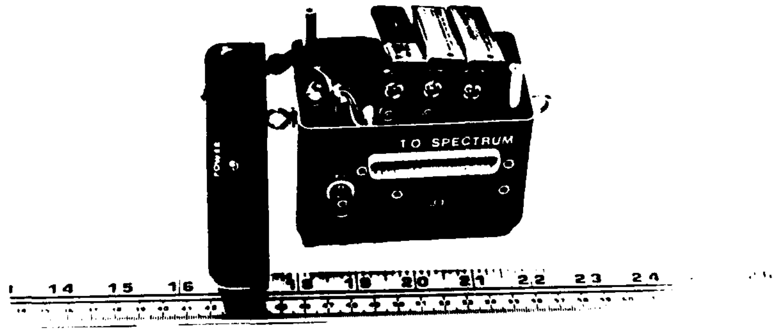


FIGURE III.2: BATTERY CONNECTORS FOR UNINTERRUPTED OPERATION

IV. OPERATION

The operation of the EEG Artifact Rejection System is relatively simple, yet there is a specific protocol that must be followed to ensure proper function.

Once the EEG and reference electrodes (Figure VII.B.15) and the nine additional electrodes (shown in Figure II.1) are attached to the subject, the unit can be powered up. This is achieved by connecting the "relay box" to the main processor unit using the cable provided. Whe.: this is done, the power indicator on the "relay box" will illuminate. A flashing light indicates a low battery. The RS-232 cable must now be connected from the processor unit to a IBM PC/XT/AT personal computer with a numeric coprocessor. A numeric coprocessor is required for the Fortran software to operate.

Type "EARS" and then a carriage return to enter the first of the two programs (see Section VII.C for software description). When the screen goes completely blank (approximately five seconds later), push the carriage return once again. The EARS menu will appear on the screen.

```
             GMS Engineering Corporation
            EEG Artifact Rejection System

    N - Channel Number Selection
    L - LED Light Level
    R - Real Time Monitoring
    P - Calibration Pulses
    I - Interrogation
    C - Correction

    Enter RESPONSE >
```

One can select the channel that the processor unit will correct by typing "N". The system will prompt the user for the desired channel number (1-24). If a carriage return is pushed without entering a number, the current channel number is selected. The default is Chann

#1. Figure IV.1 delineates the correspondence between the channel numbers (1-24), the 37-pin "D" connector pins and the normal EEG derivations connected to those pins.

GMS EEG CHANNEL #	37 PIN D CONNECTOR PIN	NORMAL EEG DERIVATION
1	1	FP1
2	20	FP2
3	2	F3
4	21	F4
5	3	C3
6	22	C4
7	4	P3
8	23	P4
9	5	01
10	24	02
11	6	F7
12	25	F8
13	7	T3
14	26	T4
15	8	T5
16	27	T6
17	28	Cz
18	10	Fz
19	29	Pz
20	11	Fpz
21	30	Oz
22	14	C3'
23	33	Cz'
24	15	C4'

FIGURE IV.1: CHANNEL NUMBERING SYSTEM

One can change the power indicator light level that appears on the "relay box" by typing "L". This will permit low level light operations. The system will prompt the user for the desired light level (1-255). The smaller the number the less intense is the light. If a carriage return is pushed without entering a number, the current light level is selected. The default is 128.

The option "R" will allow the user to monitor the three EOG channels and the selected EEG channel from the outputs on the EARS unit. To exit this routine, just push any key on the PC keyboard. This will bring the user back to the main menu.

The option "P" will allow the user to monitor the three EOG channels and the selected EEG channel from the outputs on the processor unit. A train of calibration pulses will ride on the outputs for approximately five minutes. This is caused by application of a single calibration pulse applied to all the input channels. The amplitude of this calibration pulse is 1 mV. Each pulse is fifty milliseconds in duration, and there is approximately one second between pulses. This aids the user in adjusting the desired gain for each channel. To exit this routine, just push any key on the PC keyboard. This will bring the user back to the main menu.

The option "I" is used for interrogating the medium (subject). This routine requires approximately two minutes. The direct drive signals will be output on the interrogation quadropole (the four electrodes on the forehead). After this interrogation process is completed, the host PC screen will prompt the user to store the appropriate data for processing. The prompts provided on the PC screen are: push 'PgDn', then type "7", and then type "drive" and carriage return. Then push the uppercase "A". The data will stream across the screen and into a file on the disk.

When the screen prompts the user to exit EARS, push 'ALT-X' and then "Y". The user will now be in DOS. The second program should be run by typing "EEG" and a carriage return. This program will prompt the user to enter the geometrical distances (in mm) from the eyes to the EOG and selected EEG electrodes, as well as the distance between the eyes and the distance from the center of the eyes to the quadropole. These should be carefully measured using a soft cloth tape measure. When these parameters are entered, the program then calculates and fine tunes the model coefficients and the medium transfer function.

When this program is finished, the screen will prompt the user to run the EARS program once again. One does this by following the same instructions as above. When the main menu appears, choose the "C" option to begin correcting the selected EEG channel. The user will be instructed to push 'PgUp', "7", and type "correct" and a carriage return. The appropriate model parameter data will be transferred to the main EARS processor unit, and the EEG correction will begin.

The RS-232 cable can now be disconnected. The analog outputs are as follows.

Output #1	-	Real Time EEG
Output #2	-	Real Time Event Trigger
Output #3	-	Delayed, Corrected EEG
Output #4	-	Delayed Event Trigger
Output #5	-	Delayed, Uncorrected EEG
Output #6	-	Delayed Horizontal EOG
Output #7	-	Delayed Vertical Upper EOG
Output #8	-	Delayed Vertical Lower EOG

The blinking of the power light on the "relay box" means that the batteries are getting low, and must be changed within the hour. The batteries can be changed WITHOUT interrupting operation by putting three new batteries on the reverse side of the battery clip, and then taking out the three old batteries. The power light should then be continuously on.

V. STORAGE

Turn off the battery power to the device by disconnecting the cable between the processor unit and the relay box. The LED indicator will extinguish.

Disconnect all electrodes and cables from the device.

Wipe off any debris from the external surfaces of the EARS unit before storage. A soft cloth dampened with water or a mild soap and water solution can be used. Do not apply organic solvents to this prototype unit.

To conserve battery life, remove the three 9V batteries from the unit. Do not leave the batteries in the unit, if long term storage is intended.

Return the unit to its original transport container or another equivalent storage/protection container.

VI. THEORY OF OPERATION

The EARS device is based on the idea that eye movements and blinks contribute to the observed EEG signals. If the electrical signal characteristics of these eye movements and blinks are known and the medium through which these signals propagate to the EEG observation sites (EEG electrode sites) is characterized, then this unwanted influence can be mathematically removed. The removal of this influence is the correction process. The mathematical model describing this correction process which is implemented in the software in the EARS device is described in this section.

The Biophysical Model. The transection of the face across the three dimensional ocular dipole field (caused by the corneo-retinal potential in the eye) yields a surface image dipole propagating on the scalp. This surface image dipole can be modelled to incorporate both the eye movement and the eye blink. The eye movement produces a symmetric dipole, while the blink produces an asymmetric dipole.

General Dipole Representation. A dipole source, symmetric or asymmetric, is the superposition of two point sources separated by a distance. The point source's electric field propagates as a function of $1/r^2$. The voltage at any point is described by V=kq/r, where k is Boltzmann's constant, and q is the amount of charge. The surface image dipole is described here.

Figure VI.1 shows two point sources separated by a distance (L). The voltage (V) appearing at point Q is derived as follows.

$$V = kq\{[m/(r-\tfrac{1}{2}L\sin\theta)]+[-n/(r+\tfrac{1}{2}L\sin\theta)]\}. \qquad (1)$$

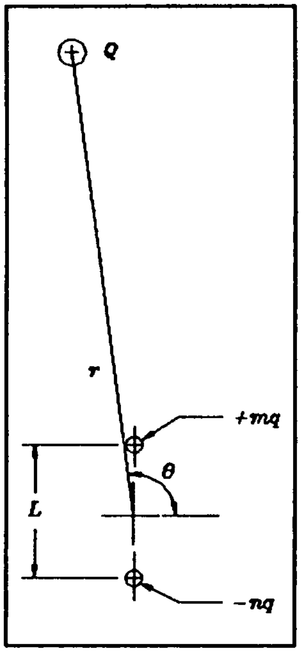


FIGURE VI.1: TWO POINT SOURCES SEPARATED BY DISTANCE L.

Rearranging Equation 1 yields

$$V = kq\{[(m-n)r+(m+n)\tfrac{1}{2}L\sin\theta]/(r^2-\tfrac{1}{4}L^2\sin^2\theta)\}. \qquad (2)$$

Since r>>L, we can simplify Equation 2:

$$V = n[(kq/r^2)\tfrac{1}{2}L\sin\theta(\alpha+1) + (kq/r)(\alpha-1)], \qquad (3)$$

where $\alpha = m/n$.

As a note, if $\alpha=1$ (eye movement) and the dipole is symmetric, Equation 3 reduces to,

$$V = (nkq/r^2)L\sin\theta = Ar^{-2}\sin\theta. \qquad (4)$$

where $A = nrqL$.

Furthermore, it is important to note that the zero-potential line of the dipole is the x-axis when $\alpha=1$ ($\sin\theta=0$). When $\alpha\neq1$, the zero-potential line becomes a circle described by,

$$x^2 + (y+G)^2 = G^2, \qquad (5)$$

where $G=\tfrac{1}{2}L[(\alpha+1)/(\alpha-1)]$.

Selection of a Facial Coordinate System. In order to spatially represent the ocular dipoles or the stimulus dipole in planar geometry, we must select a coordinate system. This is shown in Figure VI.2. The point, Q, in this figure represents an electrode. The subscript L is used to show reference to the left eye, the subscript R is used to reference the right eye. The electrode is a distance β_L from the left eye and β_R from the right eye. Reference to the stimulation dipole is indicated by S. Our facial coordinate system has its origin at the geometric center of the two eyes (which are separated by a distance z). The stimulus dipole is located a distance h above the origin. The electrode is a distance r from the origin of the coordinate system. The stimulation dipole lies on the y-axis as the eyes lie on the x-axis.

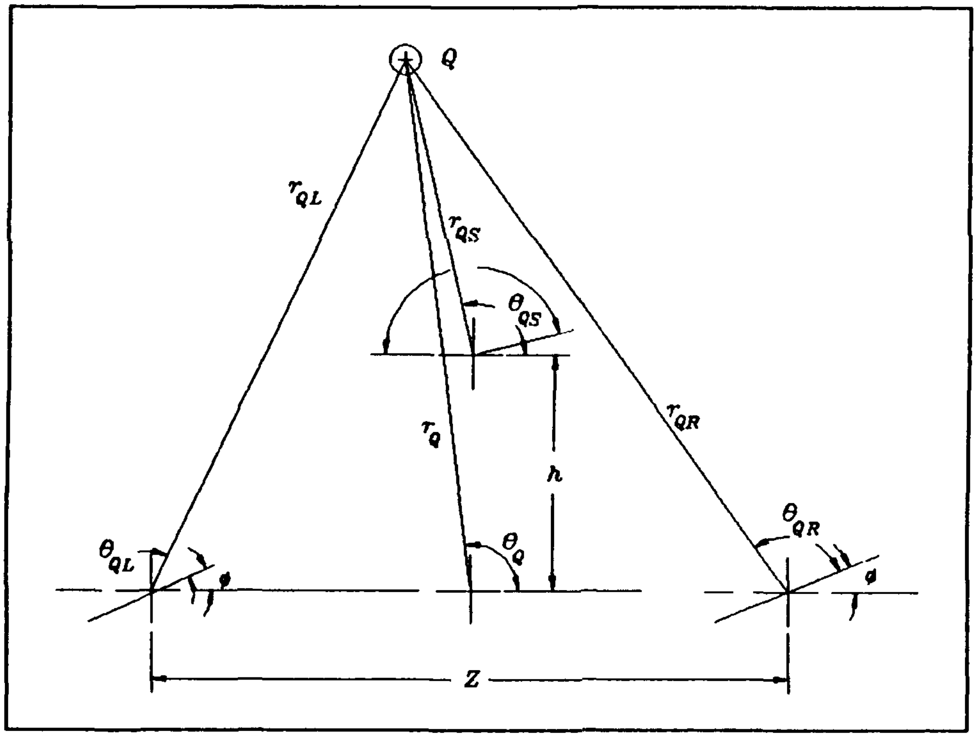


FIGURE VI.2: COORDINATE TRANSFORMATION APPLIED TO POINT Q.

Spatial Resolution of the Bi-ocular Dipoles. Using our coordinate system and dipole representation described above, we will model the two ocular dipoles as one complex mathematical function based at the origin of the coordinate system.

From the law of cosines:

$$\beta_L = [r^2 + \tfrac{1}{2}Z^2 + rZ\cos\theta]^{\frac{1}{2}} \qquad (6)$$

$$\beta_R = [r^2 + \tfrac{1}{2}Z^2 - rZ\cos\theta]^{\frac{1}{2}} \qquad (7)$$

From the law of sines:

$$\gamma_L = -\phi + \sin^{-1}[(r/\beta_L)\sin\theta] \qquad (8)$$

$$\gamma_R = \pi-\phi - \sin^{-1}[(r/\beta_R)\sin\theta] \qquad (9)$$

where: ϕ = angle of the ocular dipoles (zero-potential line).

We now substitute these identities (Eqns. 6-9) into the dipole equation defined earlier (Eqn. 3) and sum the two ocular dipoles to result in one function. We obtain this, in a general form, for any electrode:

$$V = \tfrac{1}{2}(\alpha+1)A\{[\beta_L^{-2}[-(1-\gamma_L^2)^{1/2}]\sin\phi+\gamma_L\cos\phi]+[\beta_R^{-2}[(1-\gamma_R^2)^{1/2}]\sin\phi+\gamma_R\cos\phi]\}+(A/L)(\alpha-1)\{\beta_L^{-1}+\beta_R^{-1}\}, \qquad (10)$$

where:

$$\beta_L = [(r)^2+(\tfrac{1}{2}Z)^2+rZ\cos\theta]^{1/2}$$

$$\beta_R = [(r)^2+(\tfrac{1}{2}Z)^2-rZ\cos\theta]^{1/2}$$

$$\gamma_L = (r/\beta_L)\sin\theta$$

$$\gamma_R = (r/\beta_R)\sin\theta$$

Spatial Representation of the Stimulus Dipoles. We can similarly describe the representation of the stimulus dipole in our new coordinate system as we have described the ocular dipoles above. Using Figure VI.2 and Equation 4:

$$V = B\{\sigma^{-2}[\eta \sin\psi - (1-\eta^2)^{1/2} \cos\psi]\} \tag{11}$$

where:

$$\sigma = [r^2 + h^2 - 2rh\sin\theta]^{1/2}$$

$$\eta = (-r/\sigma)\cos\theta$$

ψ = angle of the stimulus dipole (an analog of ϕ)

Equations 10 & 11 and the associated identities are the basis of the mathematical model which will be used in the calculation of the transfer function.

Mathematical Relationship Between Resultant Ocular Dipoles & Stimulus Dipoles. We can now use our basic equations and our coordinate system to correct the putative transfer function measured by surface dipoles. The EOG artifact correction equation in the frequency domain is:

$${}^{corr}V_{EEG} = {}^{obs}V_{EEG} - {}^{obs}V_{EOG}\,[S_{EEG}/S_{EOG}]\,D \tag{12}$$

where D is the geometrical correction factor between the stimulus dipole and the ocular dipoles. S denotes the surface dipole stimulation response and ${}^{obs}V$ denotes the naturally occurring response. The subscript "EEG" and "EOG" refer to the electrode recording the response; the superscripts "corr" and "obs" refer to the corrected and observed potential, respectively.

We can obtain D by manipulation of the equations described above.

$$D = \frac{\dfrac{\{\frac{1}{2}(\alpha+1)[[\beta_L^{-2}[-(1-\gamma_L^2)^{1/2}]\sin\phi+\gamma_L\cos\phi]+[\beta_R^{-2}[(1-\gamma_R^2)^{1/2}]\sin\phi+\gamma_R\cos\phi]]+((\alpha-1)/L)[\beta_L^{-1}+\beta_R^{-1}]\}_{EEG}}{\{\frac{1}{2}(\alpha+1)[[\beta_L^{-2}[-(1-\gamma_L^2)^{1/2}]\sin\phi+\gamma_L\cos\phi]+[\beta_R^{-2}[(1-\gamma_R^2)^{1/2}]\sin\phi+\gamma_R\cos\phi]]+((\alpha-1)/L)[\beta_L^{-1}+\beta_R^{-1}]\}_{EOG}}}{\dfrac{\sigma^{-2}[\eta\sin\psi-(1-\eta^2)^{1/2}\cos\psi]_{EEG}}{\sigma^{-2}[\eta\sin\psi-(1-\eta^2)^{1/2}\cos\psi]_{EOG}}} \tag{13}$$

where,
$\beta_L = [(r)^2+(\frac{1}{2}Z)^2+rZ\cos\theta]^{1/2}$,
$\beta_R = [(r)^2+(\frac{1}{2}Z)^2-rZ\cos\theta]^{1/2}$,
$\gamma_L = (r/\beta_L)\sin\theta$,
$\gamma_R = (r/\beta_R)\sin\theta$,
$\sigma = [r^2 + h^2 - 2rh\sin\theta]^{1/2}$,
$\eta = (-r/\sigma)\cos\theta$,

$$\phi = \begin{cases} 0° \text{ f}\jmath\text{r vertical EOG} \\ 90° \text{ for horizontal EOG} \end{cases}$$

$$\psi = \begin{cases} 0° \text{ for vertical interrogation pulse} \\ 90° \text{ for horizontal interrogation pulse} \end{cases}$$

$\alpha = m/n =$ (obtained in real time as $EOG_{vertical}^{upper}$ / $EOG_{vertical}^{lower}$).

We measure z and h, as well as β_L and β_R for each electrode (EEG and EOG). We then calculate r and θ for each electrode, and then calculate γ_L, γ_R, σ, and η for each electrode. Finally, we calculate D's for each EEG/EOG electrode combination. This permits correction of the observed EEG in accordance with Equation 12. Figure VI.3 shows an example of a correction. The cross-correlation between the observed EEG and the vertical EOG was 0.75; the cross-correlation between the corrected EEG and the vertical EOG was 0.017.

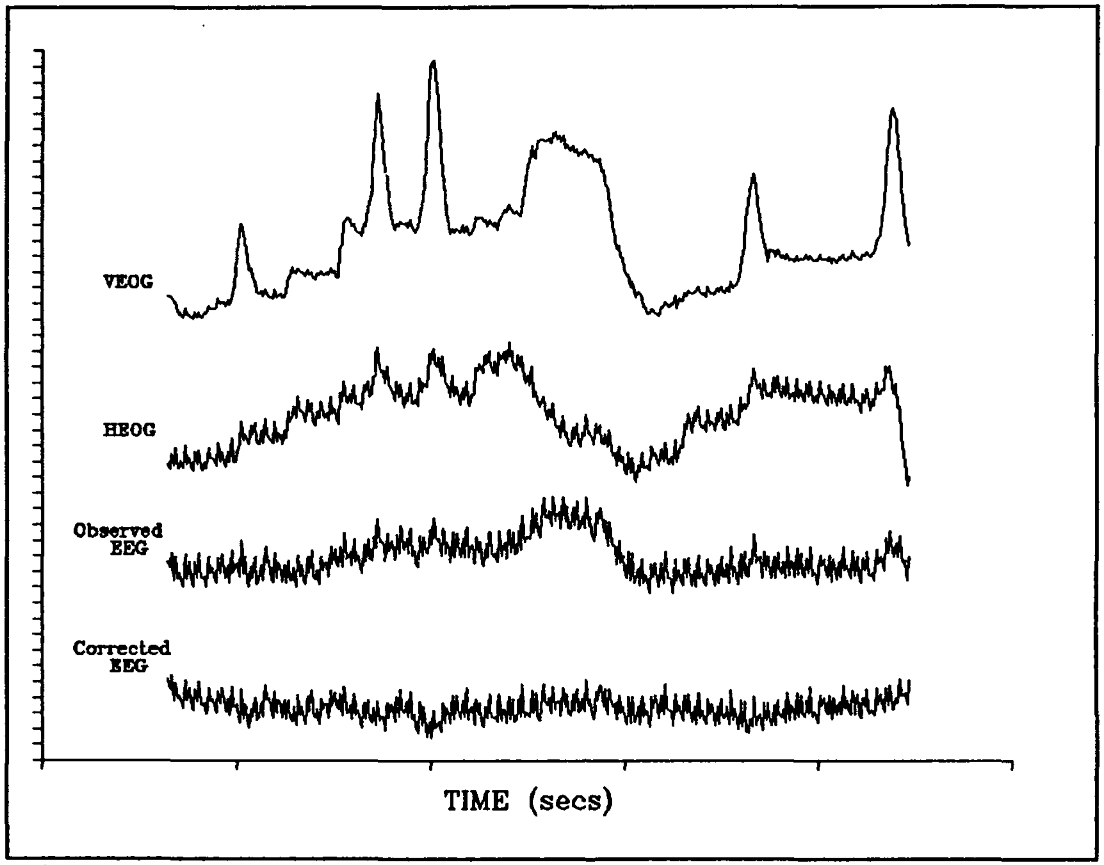


FIGURE VI.3: OBSERVED AND CORRECTED EEG.

VII. TROUBLESHOOTING GUIDE

A. GENERAL

The general troubleshooting protocol of the EARS system is extremely simple. If the power light is flashing, the batteries need to be changed. If the output levels become "flat" (no signal), the batteries need to be changed. If the batteries are new, then the system musι be serviced by authorized personnel.

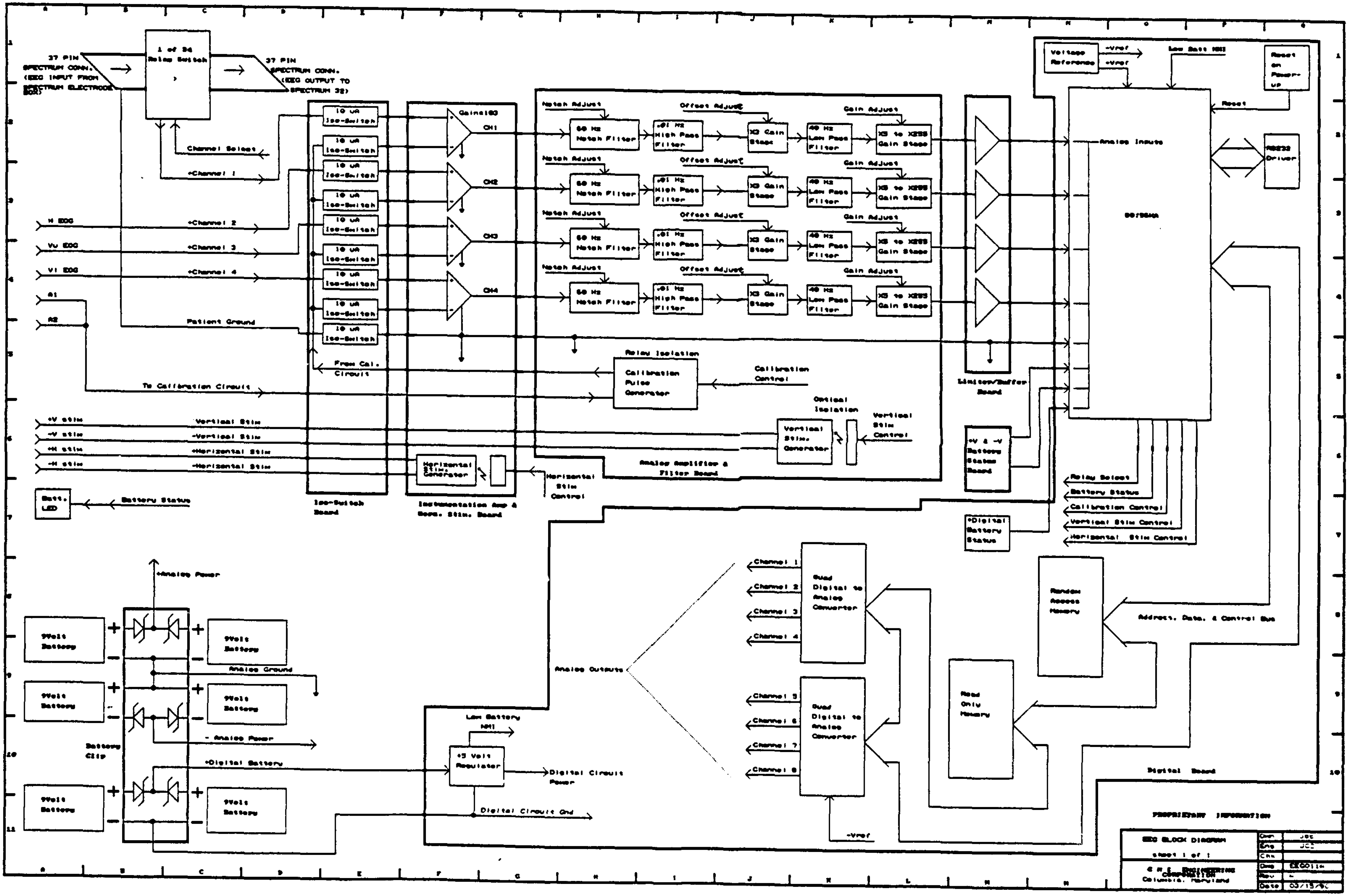
B. HARDWARE DESCRIPTION

The hardware schematics are shown in Figures VII.B.2 through VII.B.15. Figure VII.B.1 is a block diagram of the complete system. Each analog channel contains four user-adjustable potentiometers. One controls the gain of the channel; and one controls the offset of the channel. The other two are for fine tuning the 60 Hz notch filter. These are factory calibrated, and should hold their calibration for several months or longer.

The calibration circuit is a floating voltage source that is switched into series with the inverting input of the instrumentation amplifier. This level can be changed by the user with a potentiometer. See Section VIII for further details.

The digital circuitry consists of a microcontroller and memory. There are digital-to-analog output converters/amplifiers which allow the user to monitor the EEG and EOG channels.

FIGURE VII.B.1: HARDWARE BLOCK DIAGRAM



PROPRIETARY INFORMATION

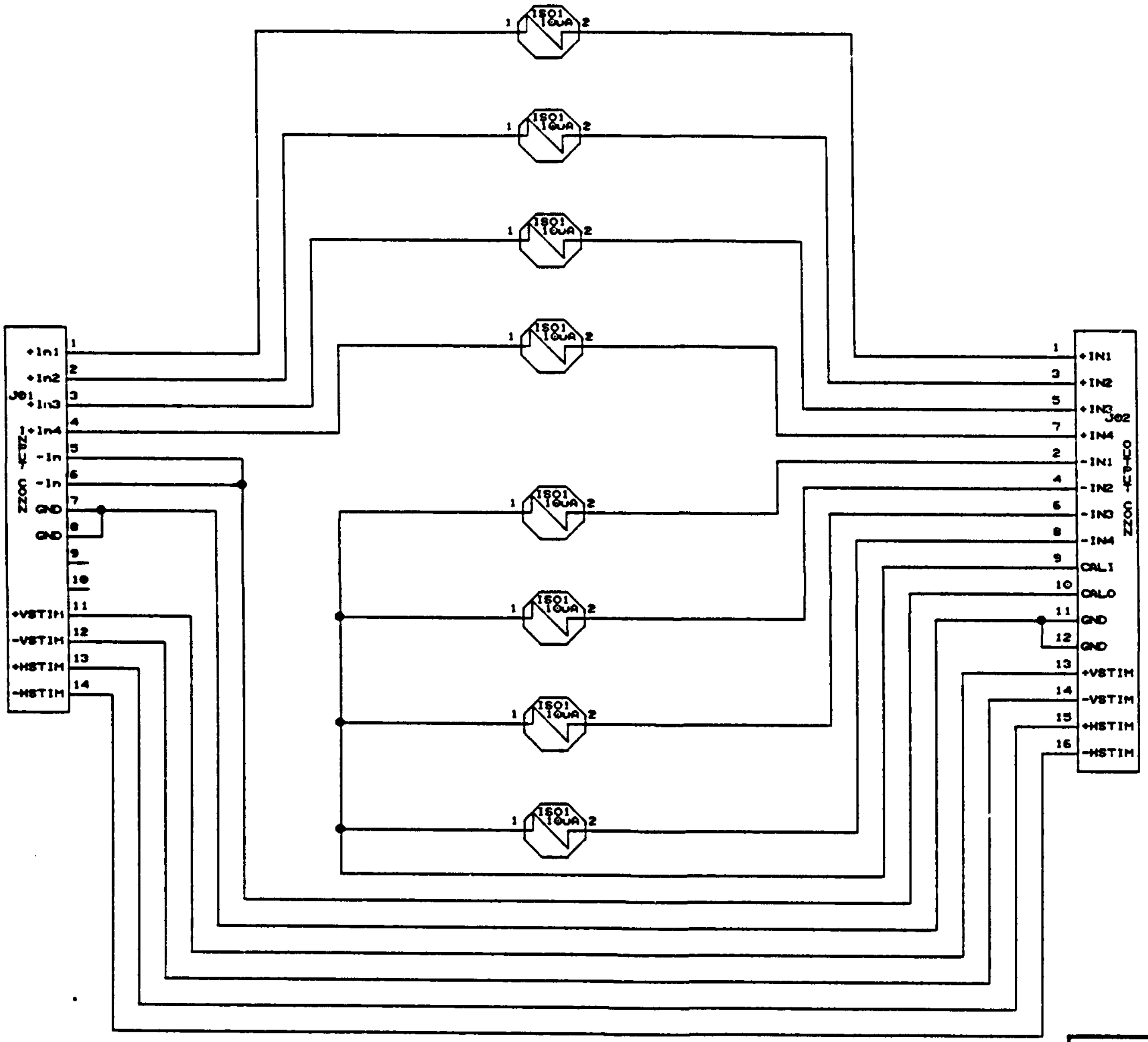
EEG BLOCK DIAGRAM

sheet 1 of 1

C R I ENGINEERING CORPORATION
Columbia, Maryland

Dwn	JEC
Eng	JCS
Chk	
Dwg	EEG0114
Rev	-
Date	03/15/90

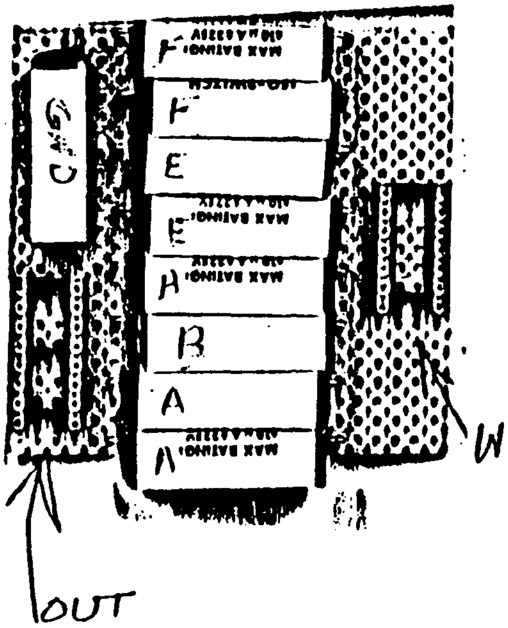
FIGURE VII.B.2: ISOSWITCH BOARD SCHEMATIC



PROPRIETARY INFORMATION

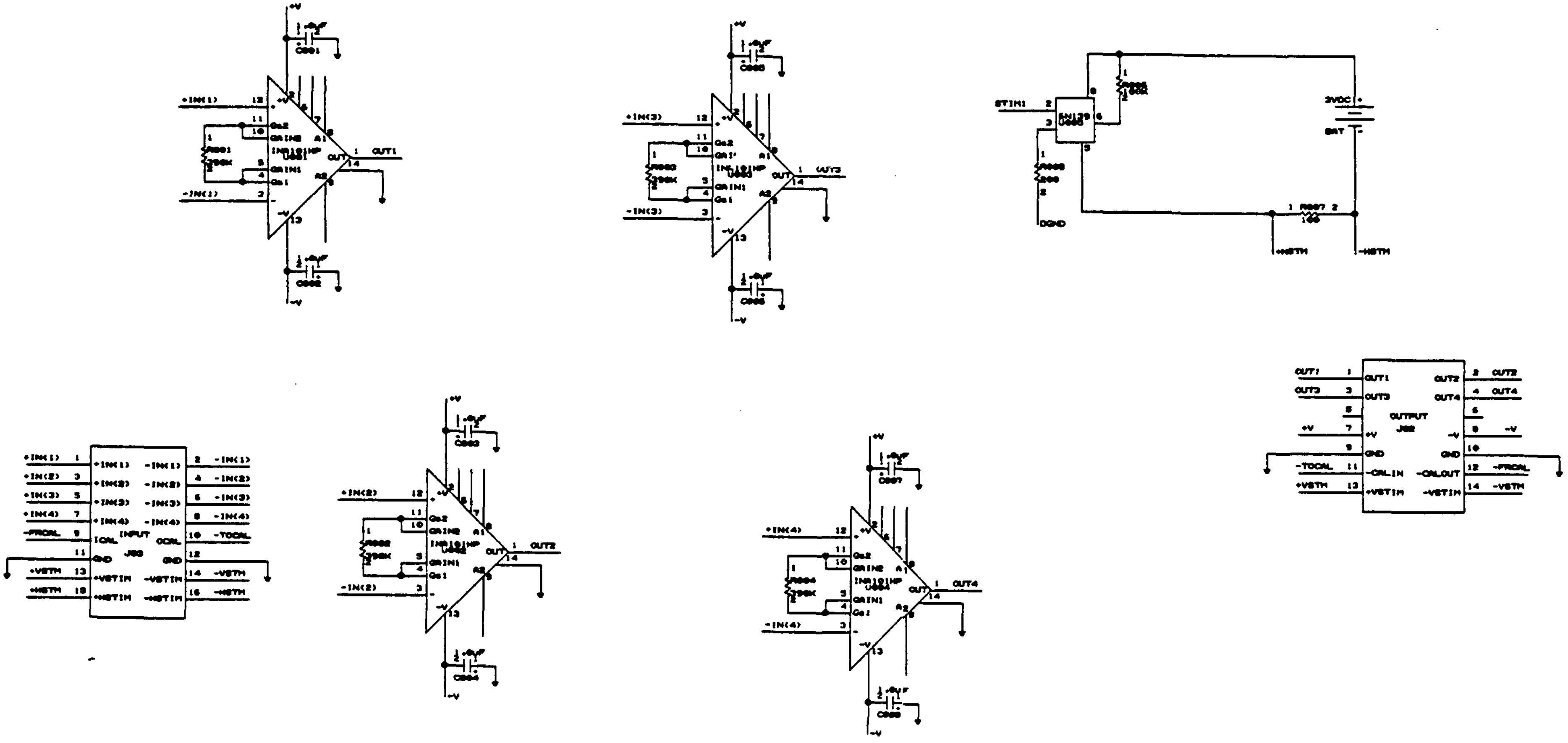
EEG ISO-SWITCH BOARD sheet 1 of 1		Dwn	JOC
		Eng	JCC
		Chk	
G M S ENGINEERING CORPORATION Columbia, Maryland		Dwg	EEG0084
		Rev	A
		Date	2/25/90

FIGURE VII.B.3: ISOSWITCH BOARD



ISO-SWITCH BOARD

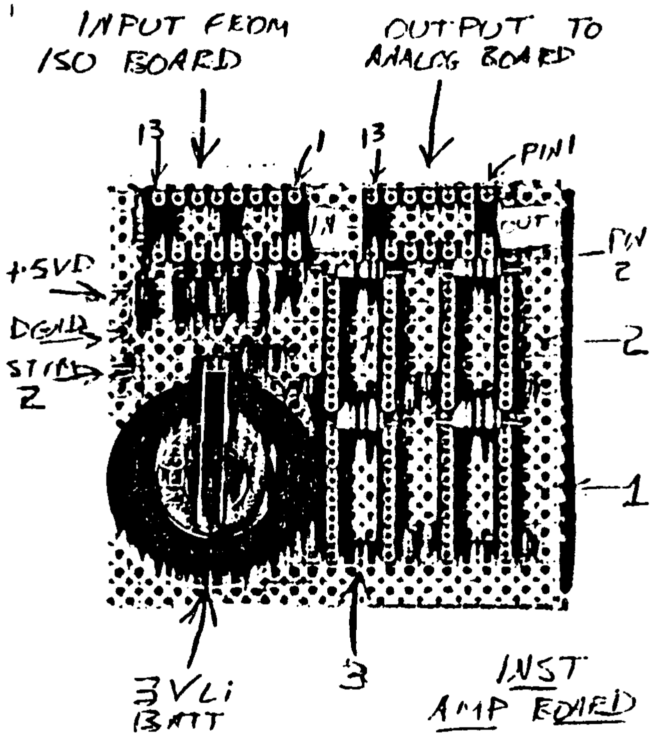
FIGURE VII.B.4: INSTRUMENTATION AMP & HORIZONTAL STIMULUS SCHEMATIC



PROPRIETARY INFORMATION

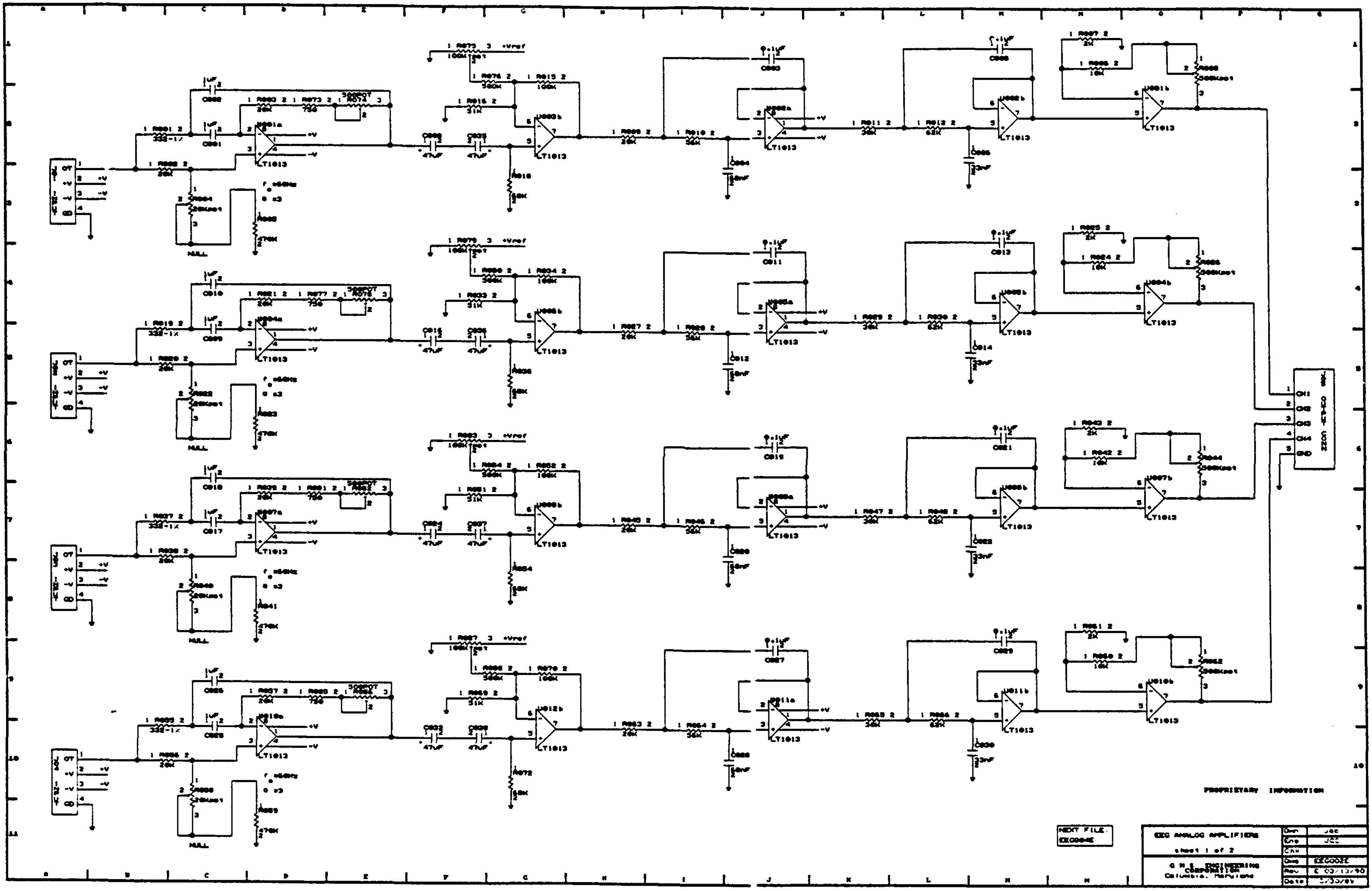
EEG INSTRUMENTATION AMP 4 HORZ STIM BOARD sheet 1 of 1	Dwn	JGC
	Eng	JCC
	Chk	
G M I ENGINEERING CORPORATION Columbia, Maryland	Dwg	EEG007A
	Rev	-
	Date	03/08/9C

FIGURE VII.B.5: INSTRUMENTATION AMP & HORIZONTAL STIMULUS BOARD



INSTRUMENTATION
AMP BOARD

FIGURE VII.B.6: ANALOG AMPLIFIERS SCHEMATIC

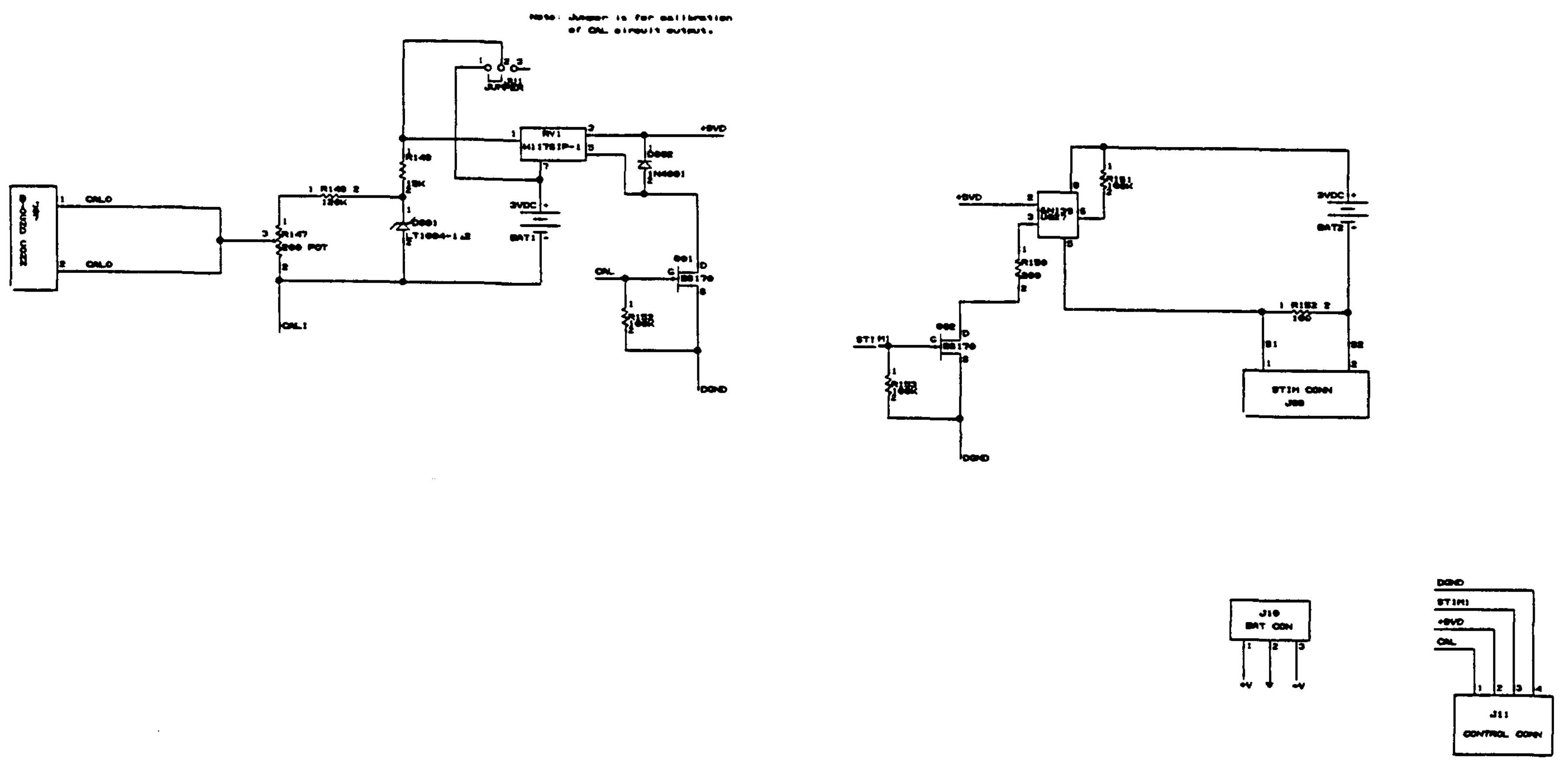


PROPRIETARY INFORMATION

NEXT FILE.
EEG004E

EEG ANALOG AMPLIFIERS		Dwn	JEC
		Eng	JEC
sheet 1 of 2		Chk	
G M S ENGINEERING CORPORATION Columbia, Maryland		Dwg	EEG002E
		Rev	E 03/13/90
		Date	5/30/89

FIGURE VII.B.7: AUTOCALIBRATION & VERTICAL AUTOSTIMULATION SCHEMATIC



Note: Jumper is for calibration of CAL circuit output.

PROPRIETARY INFORMATION

EEC AUTOCAL. & AUTOSTIM	Dwn	JCC
sheet 2 of 2	Eng	JCC
	Chk	
C M S ENGINEERING CORPORATION Columbia, Maryland	Dwg	EEG0041
	Rev	E 03/13/90
	Date	03/31/8-

FIGURE VII.B.8: ANALOG AMPLIFIER/AUTOCAL/AUTOSTIM BOARD SILKSCREEN

GMS ENGINEERING CORP.

ANALOG BOARD

AUTOMATED DESIGN SERVICES | 05-15-89

SILKSCREEN | W028

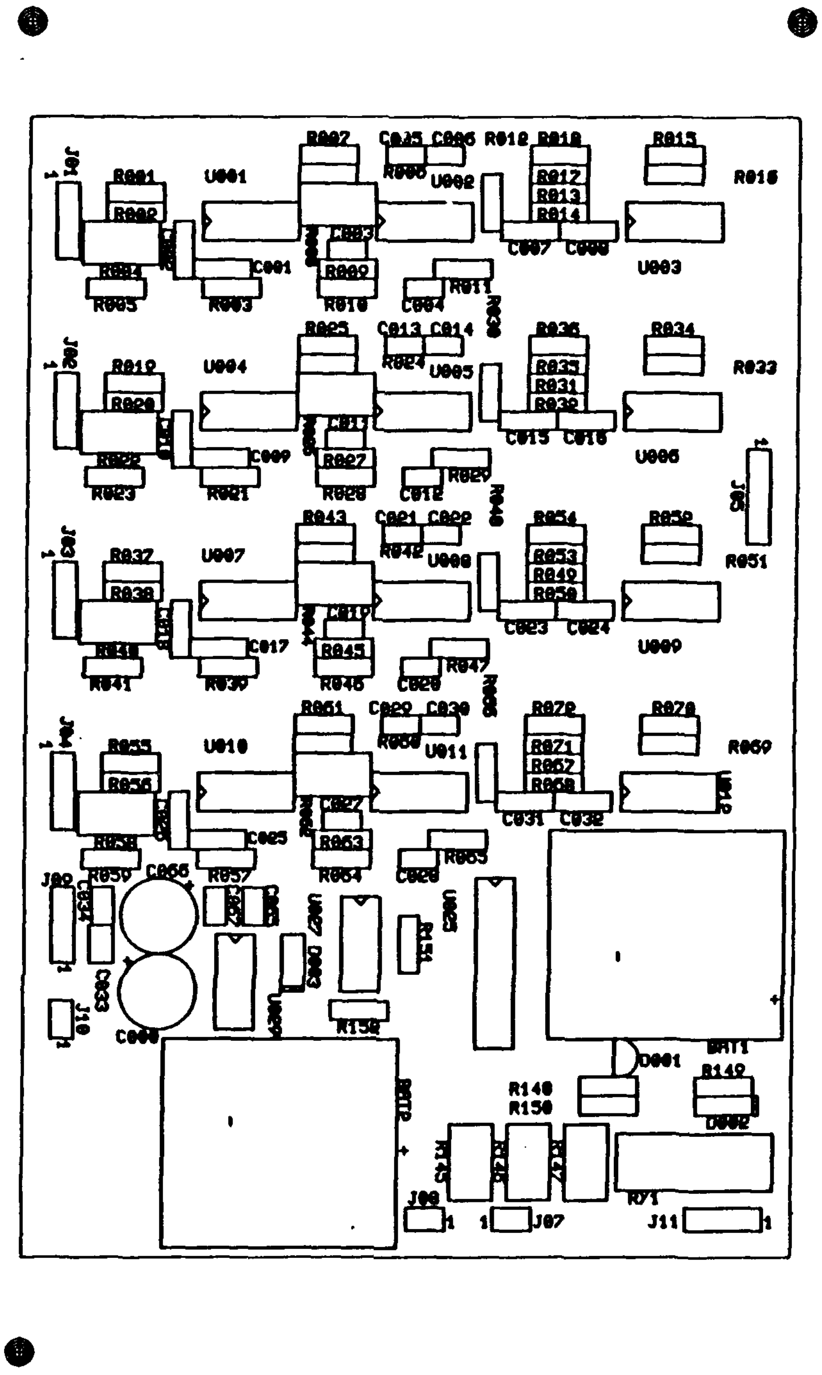


FIGURE VII.B.9: DIGITAL CIRCUIT SCHEMATIC

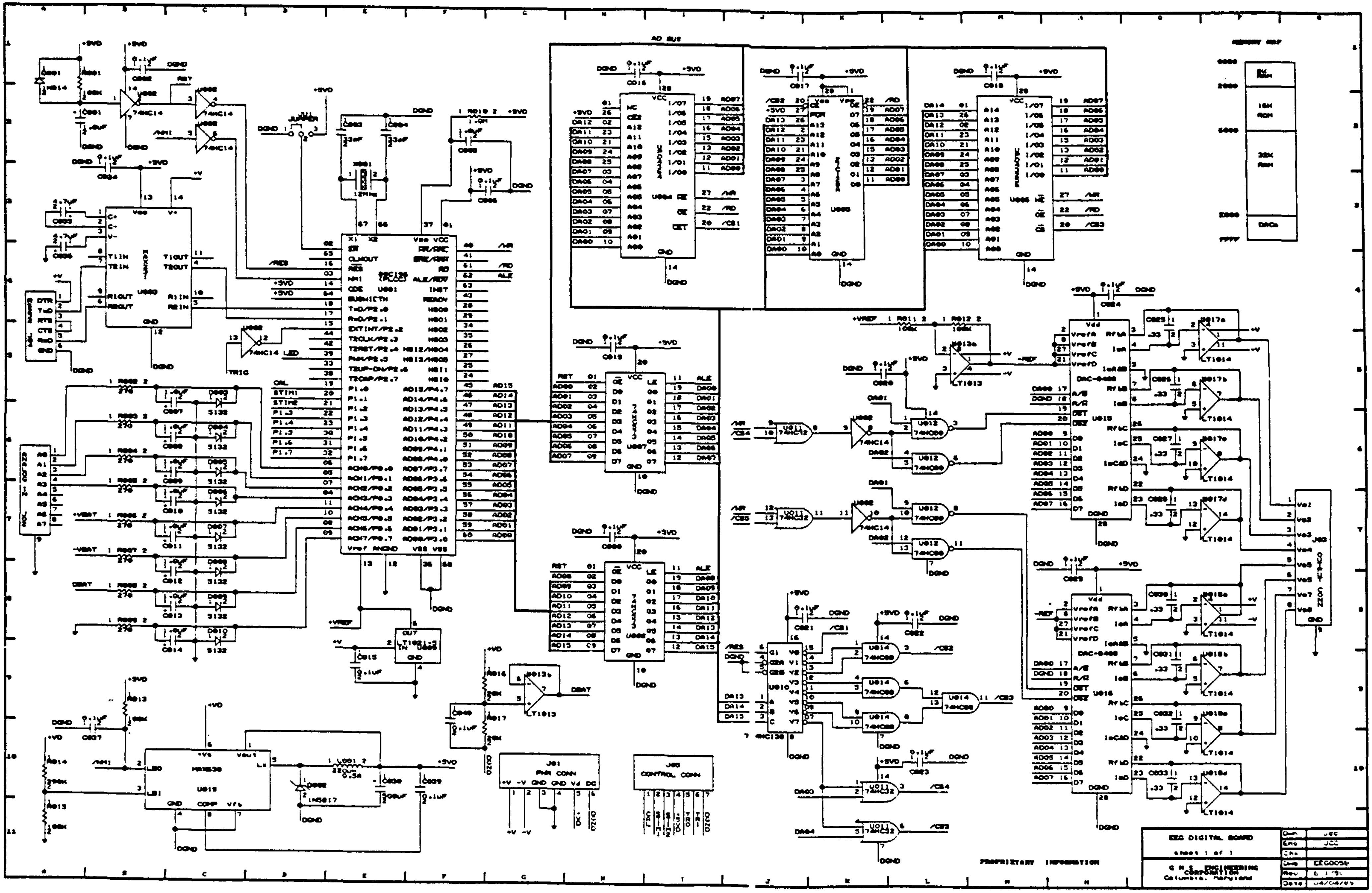
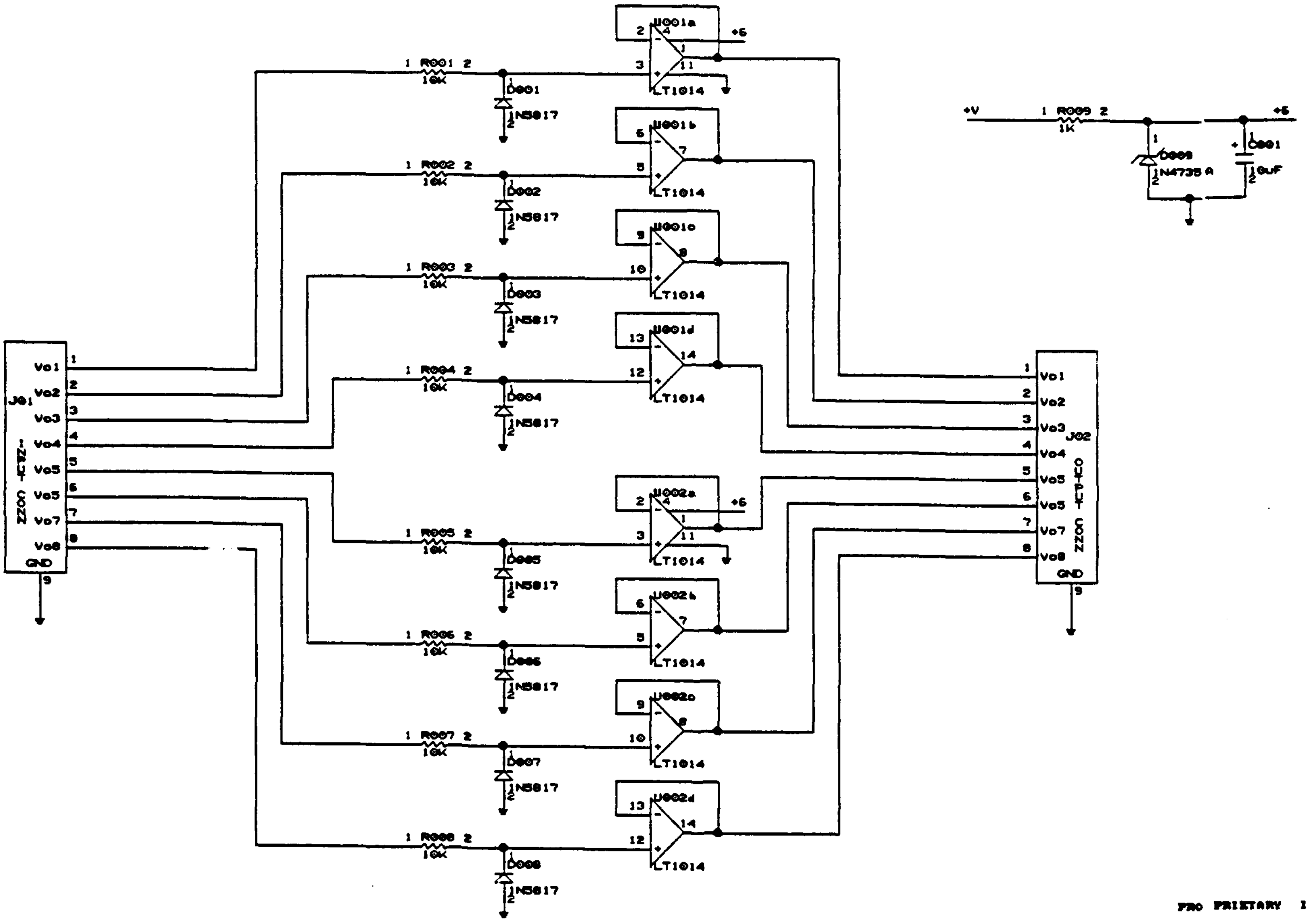

AD BUS
MEMORY MAP
0000
2000
6000
E000
FFFF
8K RAM
16K ROM
32K RAM
DACs
80C196 (PLCC) U001
MAX232 U003
U004
U005
U006
U007
U008
U010 74HC138
U015 DAC-8408
U016 DAC-8408
J02 CH-8-VOZZ
LT1014
LT1013
74HC14
74HC08
74HC32
MAX638 U019
LT1021-5 U009
1N5817
12MHz
JUMPER
TRIG
LED
+5VD
DGND
+VREF
-REF
+VBAT
-VBAT
DBAT
OUZO
/RES
/WR
/RD
ALE
/NMI
RST
J01 PWR CONN
J03 CONTROL CONN
+V -V GND GND Vd DG
MODEM PORT
DTR TxD RTS CTS RxD GND
A0 A1 A2 A3 A4 A5 A6 A7
PROPRIETARY INFORMATION
EEG DIGITAL BOARD
sheet 1 of 1
G M I ENGINEERING CORPORATION
Columbia, Maryland
Dwn JCC
Eng JCC
Chk
Dwg EEG005
Rev E 1/91
Date 04/04/85

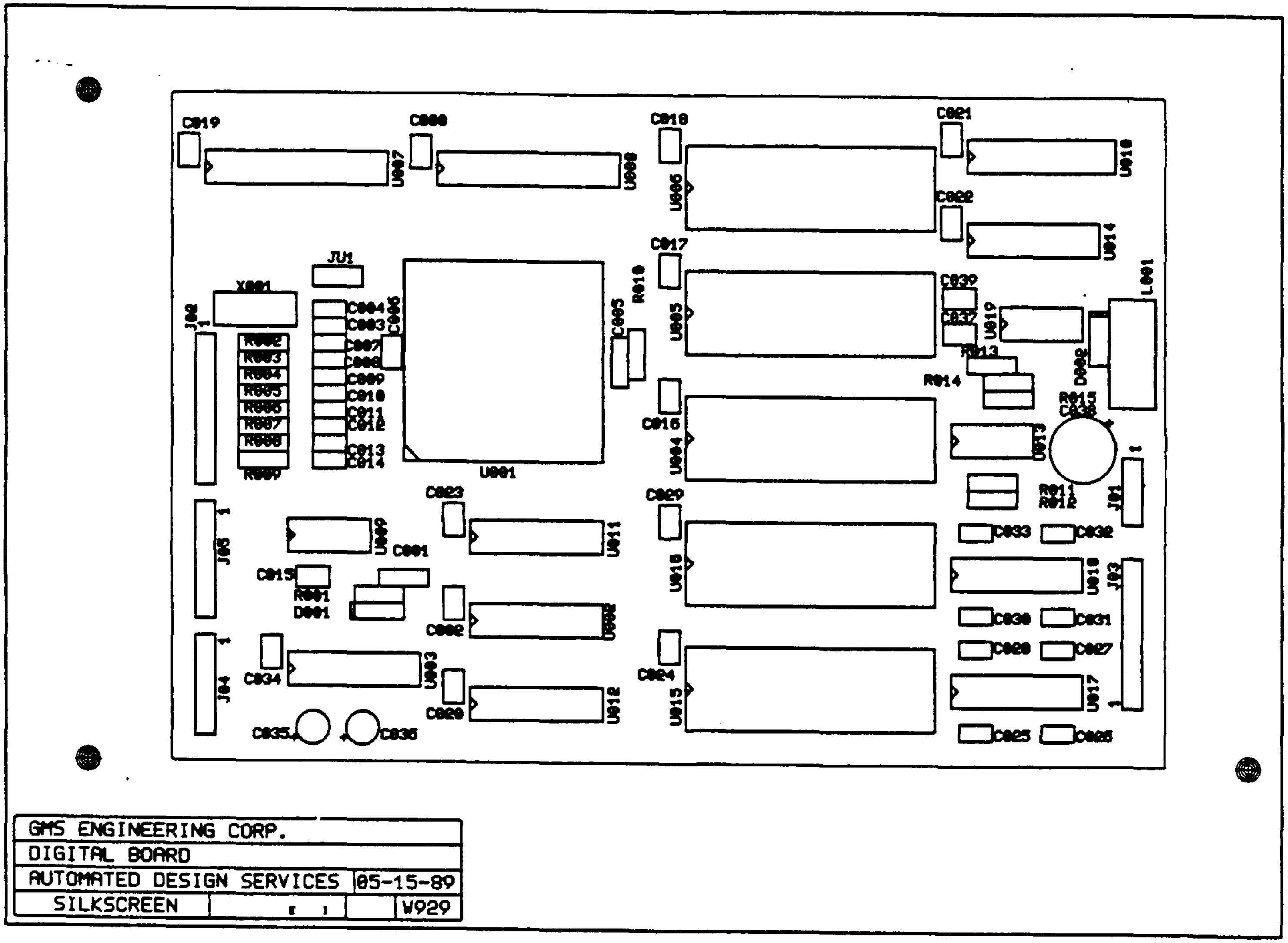
FIGURE VII.B.10: ANALOG INPUT SIGNAL LIMITER/BUFFER SCHEMATIC



PROPRIETARY INFORMATION

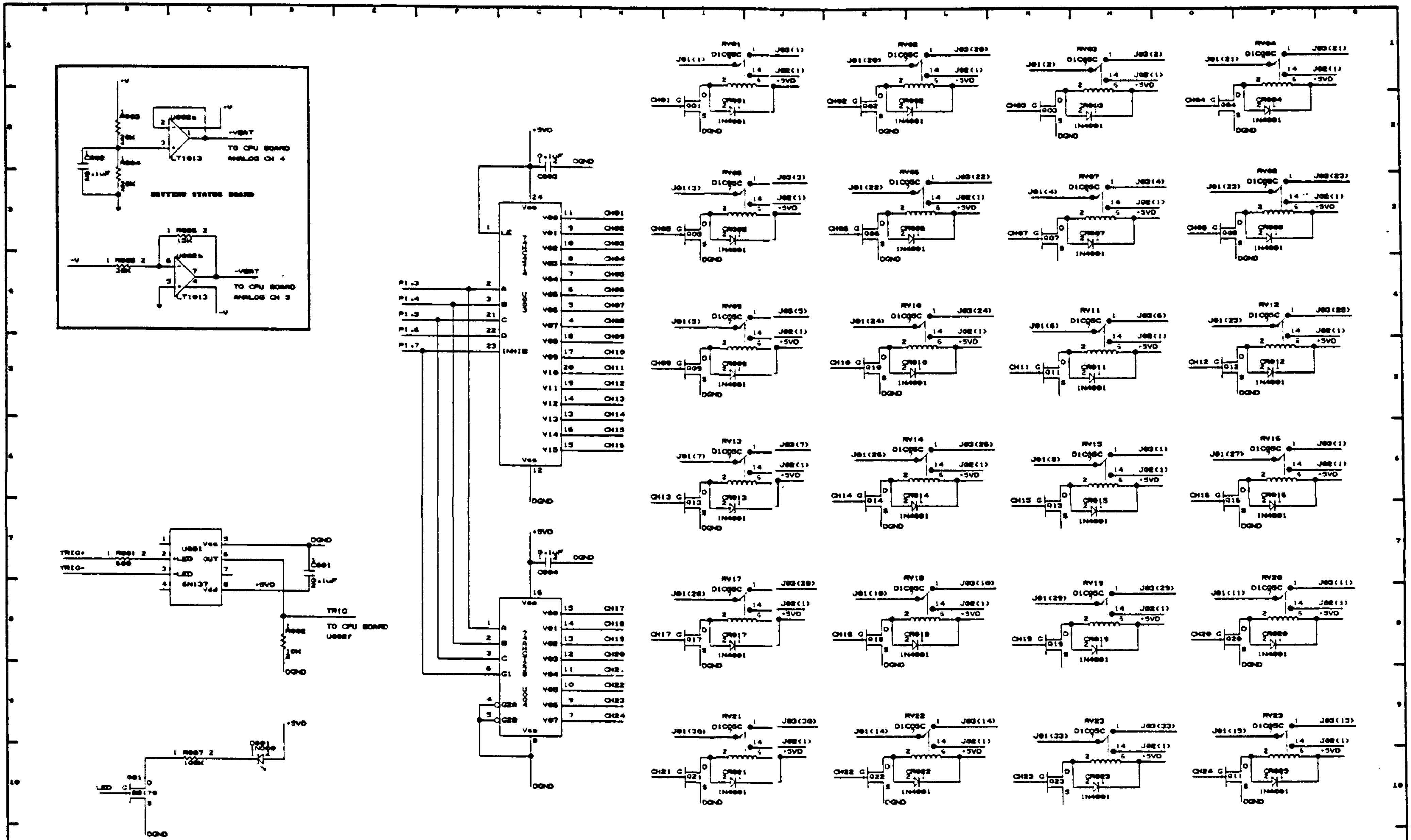
EEG LIMITER/BUFFER BOARD		Dwn	JOC
		Eng	JCC
sheet 1 of	1	Chk	
C M S ENGINEERING CORPORATION Columbia, Maryland		Dwg	EEG006A
		Rev	A
		Date	8/28/85

FIGURE VII.B.11: DIGITAL BOARD SILKSCREEN



GMS ENGINEERING CORP.
DIGITAL BOARD
AUTOMATED DESIGN SERVICES 05-15-89
SILKSCREEN W929

FIGURE VII.B.12: RELAY BOX AUXILIARY CIRCUIT SCHEMATICS


-V
R003
20K
C002
0.1uF
R004
20K
U002a
+V
-VBAT
TO CPU BOARD
ANALOG CH 4
LT1013
BATTERY STATUS BOARD
1 R005 2
13K
-V
1 R006 2
39K
U002b
-VBAT
TO CPU BOARD
ANALOG CH 3
LT1013
-V
TRIG+
TRIG-
1 R001 2
560
U001
6N137
+LED
-LED
Vss
OUT
Vdd
+5VO
DGND
C001
0.1uF
TRIG
TO CPU BOARD
U0027
R002
10K
DGND
+5VO
D001
1 R007 2
100K
Q01
LED
SB170
DGND
+5VO
0.1uF
C003
DGND
U003
74HC4514
Vdd
Vss
LE
P1.3
P1.4
P1.5
P1.6
P1.7
A
B
C
D
INHIB
V00
V01
V02
V03
V04
V05
V06
V07
V08
V09
V10
V11
V12
V13
V14
V15
CH01
CH02
CH03
CH04
CH05
CH06
CH07
CH08
CH09
CH10
CH11
CH12
CH13
CH14
CH15
CH16
+5VO
0.1uF
C004
DGND
U004
74AHCT238
G1
G2A
G2B
CH17
CH18
CH19
CH20
CH21
CH22
CH23
CH24
RV01 D1C05C J01(1) J03(1) J02(1) +5VO CH01 G Q01 CR001 1N4001 DGND
RV02 D1C05C J01(20) J03(20) J02(1) +5VO CH02 G Q02 CR002 1N4001 DGND
RV03 D1C05C J01(2) J03(2) J02(1) +5VO CH03 G Q03 CR003 1N4001 DGND
RV04 D1C05C J01(21) J03(21) J02(1) +5VO CH04 G Q04 CR004 1N4001 DGND
RV05 D1C05C J01(3) J03(3) J02(1) +5VO CH05 G Q05 CR005 1N4001 DGND
RV06 D1C05C J01(22) J03(22) J02(1) +5VO CH06 G Q06 CR006 1N4001 DGND
RV07 D1C05C J01(4) J03(4) J02(1) +5VO CH07 G Q07 CR007 1N4001 DGND
RV08 D1C05C J01(23) J03(23) J02(1) +5VO CH08 G Q08 CR008 1N4001 DGND
RV09 D1C05C J01(5) J03(5) J02(1) +5VO CH09 G Q09 CR009 1N4001 DGND
RV10 D1C05C J01(24) J03(24) J02(1) +5VO CH10 G Q10 CR010 1N4001 DGND
RV11 D1C05C J01(6) J03(6) J02(1) +5VO CH11 G Q11 CR011 1N4001 DGND
RV12 D1C05C J01(25) J03(25) J02(1) +5VO CH12 G Q12 CR012 1N4001 DGND
RV13 D1C05C J01(7) J03(7) J02(1) +5VO CH13 G Q13 CR013 1N4001 DGND
RV14 D1C05C J01(26) J03(26) J02(1) +5VO CH14 G Q14 CR014 1N4001 DGND
RV15 D1C05C J01(8) J03(1) J02(1) +5VO CH15 G Q15 CR015 1N4001
RV16 D1C05C J01(27) J03(1) J02(1) +5VO CH16 G Q16 CR016 1N4001 DGND
RV17 D1C05C J01(28) J03(28) J02(1) +5VO CH17 G Q17 CR017 1N4001 DGND
RV18 D1C05C J01(10) J03(10) J02(1) +5VO CH18 G Q18 CR018 1N4001 DGND
RV19 D1C05C J01(29) J03(29) J02(1) +5VO CH19 G Q19 CR019 1N4001
RV20 D1C05C J01(11) J03(11) J02(1) +5VO CH20 G Q20 CR020 1N4001 DGND
RV21 D1C05C J01(30) J03(30) J02(1) +5VO CH21 G Q21 CR021 1N4001 DGND
RV22 D1C05C J01(14) J03(14) J02(1) +5VO CH22 G Q22 CR022 1N4001 DGND
RV23 D1C05C J01(33) J03(33) J02(1) +5VO CH23 G Q23 CR023 1N4001
RV23 D1C05C J01(13) J03(13) J02(1) +5VO CH24 G Q11 CR023 1N4001 DGND

Note: All FETs are type SB170

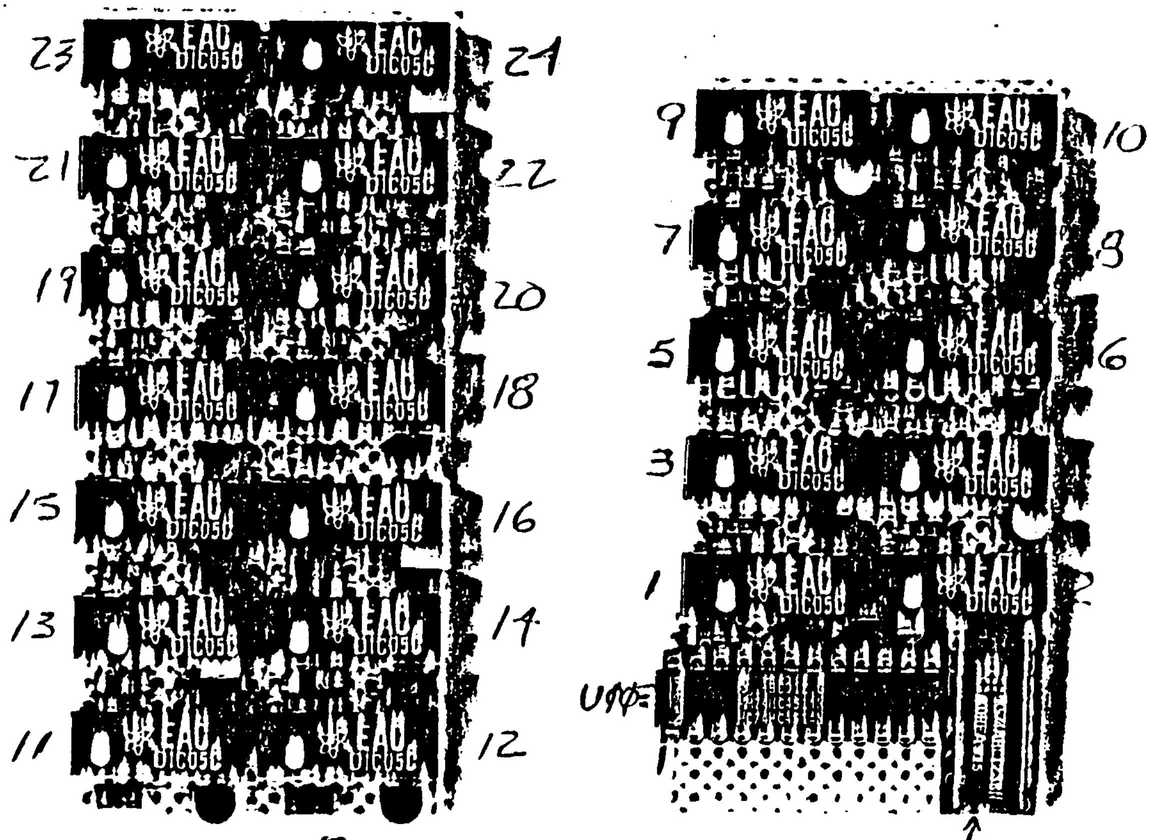
PROPRIETARY INFORMATION

EEG AUXILARY BOARDS
(RELAY BOX)
sheet 1 of 2

G M S ENGINEERING
CORPORATION
Columbia, Maryland

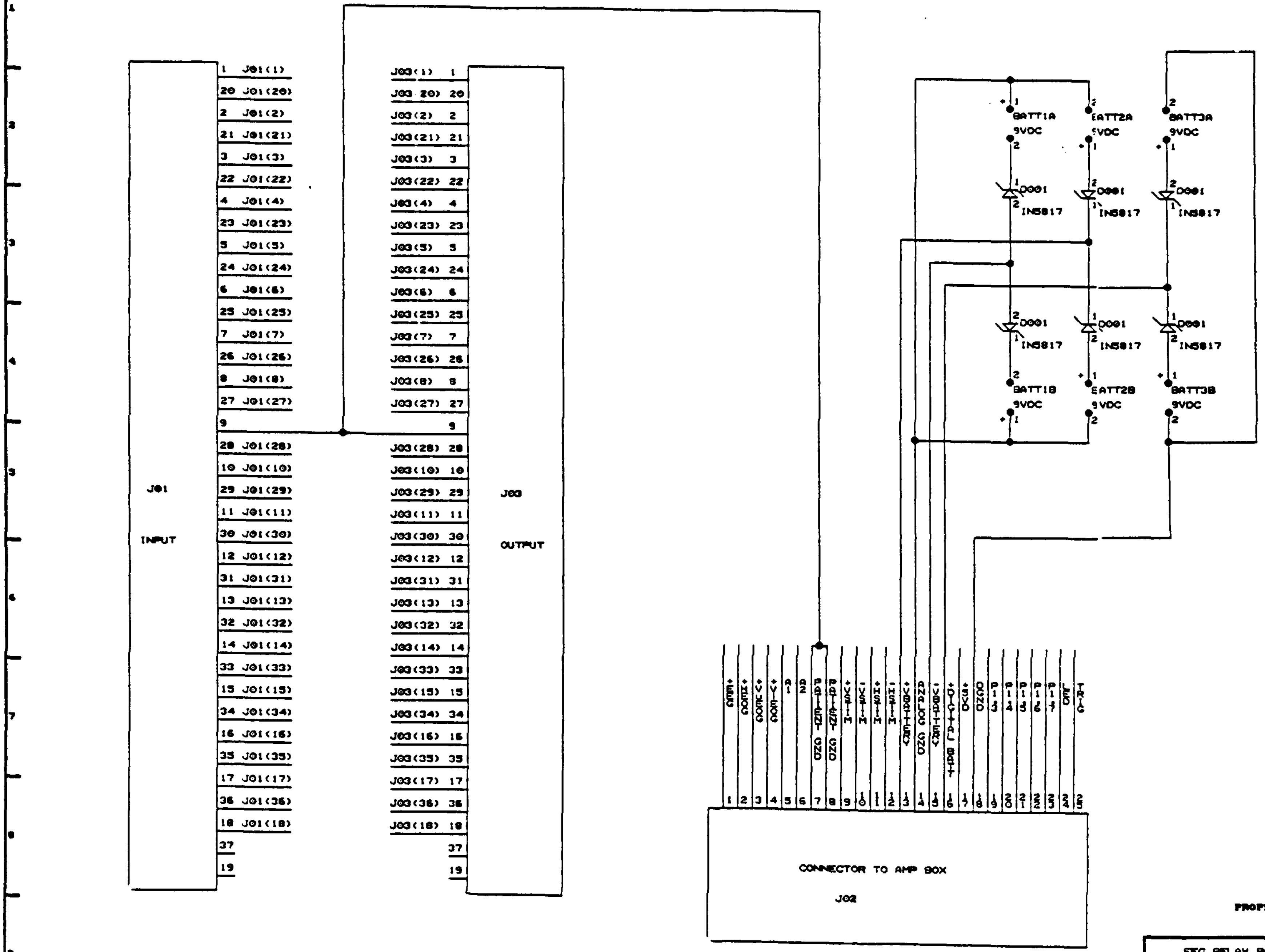
Dwn	.GG
Eng	.CC
Chk	
Dwg	EEG009A
Rev	H
Date	3/13/90

FIGURE VII.B.13: RELAY BOARDS


23
24
21
22
19
20
17
18
15
16
13
14
11
12
9
10
7
8
5
6
3
1
2
U1Ø
JØØ4
EAO
D1C050

RELAY BOX

FIGURE VII.B.14: RELAY BOX CONNECTOR SCHEMATIC

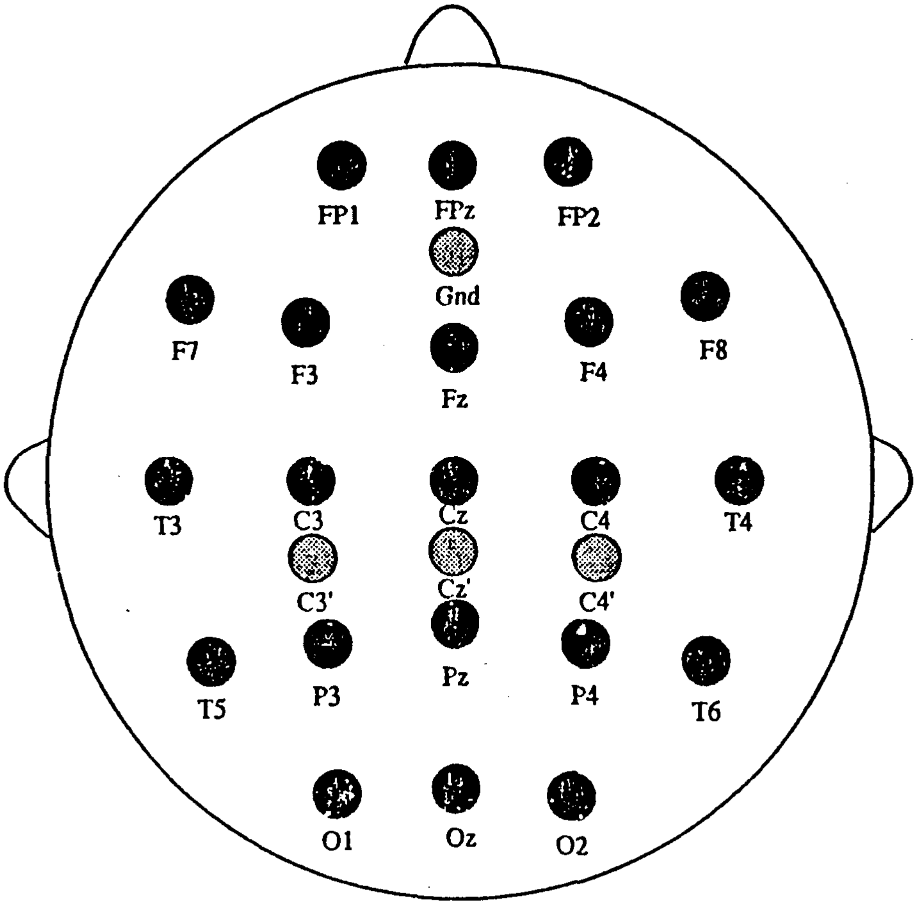


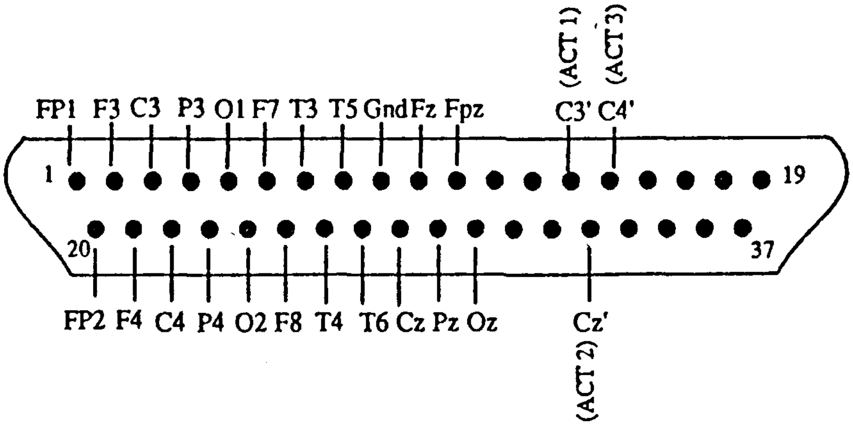
PROPRIETARY INFORMATION

EEG RELAY BOX		Dwn	JGO
sheet 2 of 2		Eng	JCC
		Chk	
G M S ENGINEERING CORPORATION Columbia, Maryland		Dwg	EEG010A
		Rev	A
		Date	03/16/90

FIGURE VII.B.15: 37 PIN "D" CONNECTOR PINOUT DESIGNATION

SPECTRUM 32 HEAD CAP CONFIGURATION





37 PIN "D" HEAD CAP CONNECTOR

C3' = ACT 1 on Spectrum 32 Headbox.
Cz' = ACT 2 on Spectrum 32 Headbox.
C4' = ACT 3 on Spectrum 32 Headbox.
Gnd = Iso Gnd on Spectrum 32 Headbox.

NOTE: In order to use the Prime electrodes (C3', Cz', or C4') you must specify the correct active input (ACT 1, 2, or 3) on the Spectrum 32.

C. SOFTWARE DESCRIPTION

There are two components of the software for the EEG Artifact Rejection System. These components are the EPROM code which is contained in the unit and the PC based code which is contained on the disk. The complete software are appended here.

The EPROM code ("EEG" written in C, and "FFT_FOR" written in assembler) consists of six parts. The first part is the serial communications routine. This allows the user to control what the unit does as well as selection of the desired channel and the LED level. This also is the vehicle for data transfer. The second part is the service of the hardware and housekeeping routines. This part is necessary for all software. The processor, memory, and peripheral circuits require specific signals and protocols. This is accomplished in the housekeeping and hardware service routines. The batteries are checked here as well. The third and fourth parts are similar to each other. They perform the real-time monitoring function. The fourth part adds the calibration pulses if the user desires them. The fifth part performs the direct interrogation. The vertical, horizontal, and calibration drives are output, and the electrode signals are recorded and stored for later processing. The last part is the application of the model for correction of the EEG.

The PC-based code ("EARS" and "EEG" which consists of "SHELL, "DCALC2", "SGM", and "FTUNE2" all written in Fortran) consists of four parts. The first part is the serial communications routine. This is the PC side of the communications described above. This program is "EARS". The second (DCALC2), third (SGM), and fourth (FTUNE2) parts are all contained in "EEG". The second part allows the user to enter the geometrical measurements, and calculates the model parameters from these measurements. The third part takes the interrogation data and calculates the medium transfer function for the specific test subject. The last part statistically fine tunes the model coefficients obtained in the second part using the transfer function obtained in the third part. The coefficients and the transfer function must be then sent back to the main processor unit before the correction can commence. This is accomplished by option "C" in "EARS".

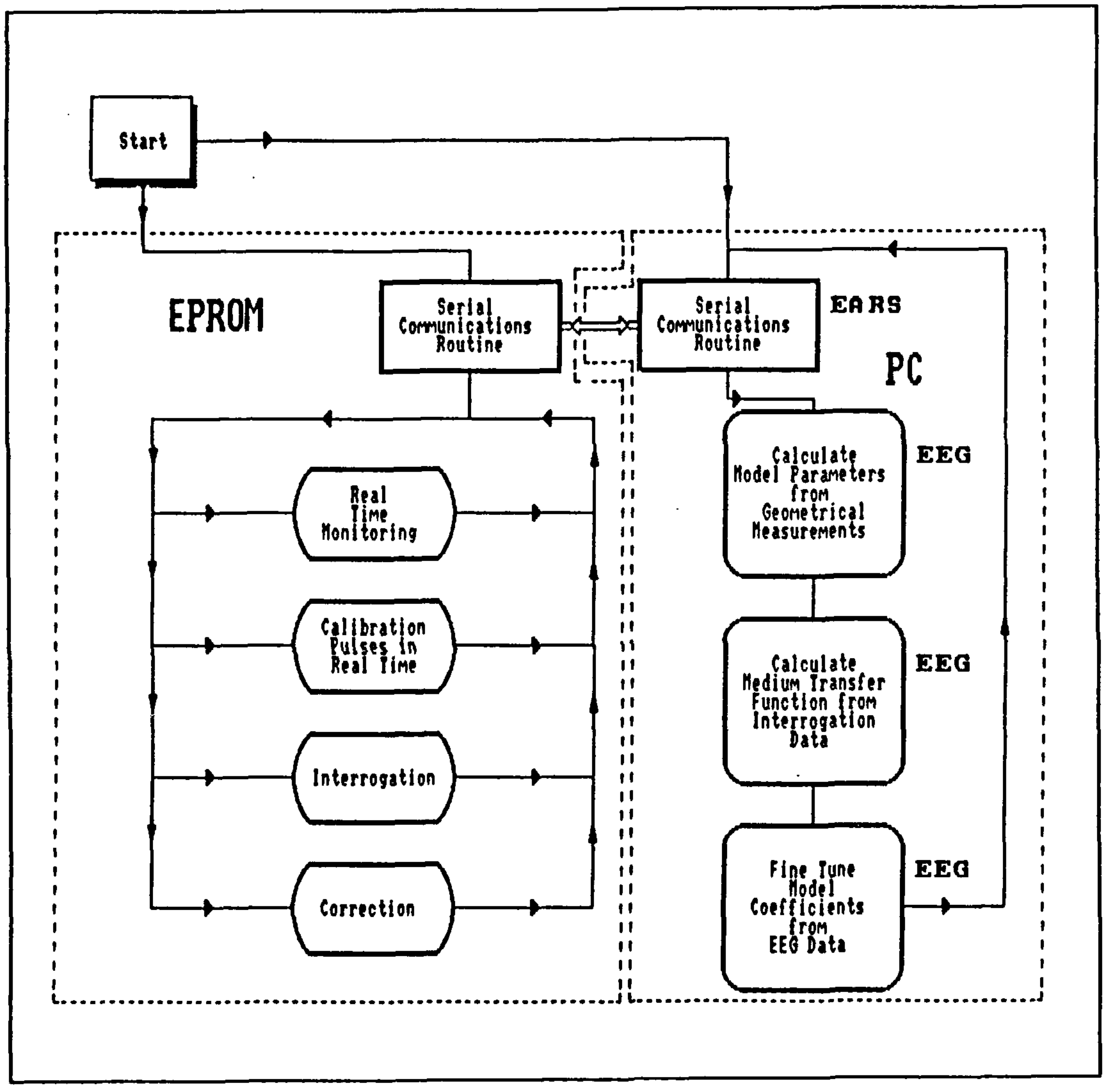

Start
EPROM
Serial Communications Routine
Real Time Monitoring
Calibration Pulses in Real Time
Interrogation
Correction
Serial Communications Routine
EARS
PC
Calculate Model Parameters from Geometrical Measurements
EEG
Calculate Medium Transfer Function from Interrogation Data
EEG
Fine Tune Model Coefficients from EEG Data
EEG

FIGURE VII.C.1: SOFTWARE BLOCK DIAGRAM.

VIII. CALIBRATION PROCEDURES

By choosing the "P" (Calibration Pulses) option on the main menu, the user can tune the gains and offsets while viewing the input signal with a common calibration pulse riding on all the channels. This amplitude of this calibration pulse can be adjusted by the user. This may be required when the channel gains are changed to the upper or lower extremes. This procedure is as follows.

The EARS main processor unit must be opened by removing the seven screws on the face opposite the potentiometers. Once the top is removed, the several printed circuit boards in the unit will become visible. On the side of the main printed circuit board closest to the RS-232 connector is a jumper and two monitoring pins. The jumper can be moved to the next position, which bypasses the relay and continuously applies the calibration battery to the circuit. The monitoring pins can be used to measure the exact voltage of the calibration pulse. A microvolt meter must be used for this purpose. The potentiometer control on the outside opposite face of the unit can be used to adjust the voltage. The jumper MUST be placed back in the factory position after this is complete and before the unit is closed.

IX.INDEX

X. APPENDICES

APPENDIX A: PROM SOFTWARE LISTING

```
DOS 3.30 (038-N) C96 COMPILER V1.1, COMPILATION OF MODULE EEG
OBJECT MODULE PLACED IN EEG.obj
COMPILER INVOKED BY: D:\196\C96\C96.EXE EEG.C96 MODEL(196) OPTIMIZE(2) REGISTERS(100)

 stmt level  incl

    1             /*
    1                          EEG.C96  -  EOG Artifact Removal System
    1                          Implemented in Intel iC96 for the 80C196KA
    1
    1                                Steven M. Falk
    1                                Jeffrey C. Sigl
    1
    1                                Created:        August 22, 1989
    1
    1                                Version No.:    1.0
    1
    1                                Last Update:    February 12, 1990
    1
    1                                GMS Engineering Corporation
    1                                8940-D Route 108
    1                                Columbia, MD  21045
    1                                (301) 995-0508
    1
    1
    1                               |-----------------------|
    1                               |      MEMORY MAP       |
    1                      0000     |-----------------------|\
    1                               | SP,SFRS,REGISTERS     | \
    1                      0100     |-----------------------|  \
    1                               |                       |   |
    1                               | EXTERNAL MEMORY       |   | 8K RAM
    1                               |                       |   |
    1                      1FFE     |-----------------------|  /
    1                               | I/O PORTS 3 & 4       | /
    1                      2000     |-----------------------|/
    1                               | LOW INTRPT VECTORS    |\
    1                      2014     |-----------------------| \
    1                               | RESERVED (INTEL)      |  \
    1                      2018     |-----------------------|   |
    1                               | CCR                   |   |
    1                      2019     |-----------------------|   |
    1                               | RESERVED (INTEL)      |   |
    1                      2020     |-----------------------|   |
    1                               | EPROM SECURITY KEY    |   |16K ROM
    1                      2030     |-----------------------|   |
    1                               | HIGH INTRPT VECTORS   |   |
    1                      2040     |-----------------------|   |
    1                               | RESERVED (INTEL)      |   |
    1                      2080     |-----------------------|   |
    1                               |                       |   |
    1                               | CODE                  |  /
    1                               |                       | /
    1                      6000     |-----------------------|/
    1                               |                       |\
    1                               |                       | \
    1                               |                       |  \
1                             | RAM                   |   |32K RAM
1                             |                       |   |
1                             |                       |  /
1                             |                       | /
1                    E000     |-----------------------|/
1                             |                       |
1                             | DACS                  |
1                             |                       |
1                    FFFF     |-----------------------|
1
1
1           Port pin assignments
1
1               Pin     Direction     Function                        P1.x=1      P1.x=0
1           --------------------------------------------------------------------------
1               P1.0    output        Cal                               ON         OFF
1               P1.1    output        Stim1                             ON         OFF
1               P1.2    output        Stim2                             ON         OFF
1               P1.3    output        Relay Address (LSB)
1               P1.4    output        Relay Address
1               P1.5    output        Relay Address
1               P1.6    output        Relay Address
1               P1.7    output        Relay Address (MSB)
1               P2.5    output        LED
1               P2.2    input         Event Trigger In
1
1
1
1           #     Input Channels          #  Stored in data_buffer[#][][]    Output Chan.
1           ----------------------------------------------------------------------------
1           0       EEG                 EEG                uEEG(t)
1           1       HEOG                          HEOG                          ETO(t)
1           2       VEOGu                         VEOGu                         cEEG(t-T)
1           3       VEOGl                         VEOGl                         ETO(t-T)
1           4                                     Event Trigger Out             HEOG(t-T)
1           5                                                                   VEOGu(t-T)
1           6                                                                   VEOGl(t-T)
1           7
1
1
1
1           This routine must be linked with:
1
1               e_int.obj (macro EI)
1               CCR.ABS (ccb)
1               user.lib (patched c96.lib)
1               fft_for.obj (the FFT)
1               cstart.obj (main module)
1               plm96.lib
1
1           i.e.,
1
1           eeg.obj,cstart.obj,ccr.abs,e_int.obj,fft_for.obj, &
1            user.lib,plm96.lib to eeg ixref &
1            ro(2000H-2013H,2018H-2018H,2030H-203FH,2080H-5FFFH) &
1            ra(1AH-1FFDH(STACK),6000H-0DFFFH)
1
```

```

rtine_flag = 0          =           real-time
rtine_flag = 1          =           interrogation
rtine_flag = 2          =           collection of epochs for fine tuning
rtine_flag = 3          =           correction
rtine_flag = 7          =           real-time with cal pulses
rtine_flag = 99         =           stop

*/



/* Headers */

#include <80C196.h>                 /* 80C196 I/O registers */
#include <ctype.h>
#include <setjmp.h>
#include <stdio.h>
#include <stdlib.h>
#include <string.h>




/* Definitions */

#define         PRE_SCALE           64

#define         BUFF_START          64
#define         BUFF_DIFF           384         /* 0.75*SAMP_NUM */
#define         CHAN_BASE           0x08        /* ADC Channel base (ADC0) */
#define         CHAN_NUM        4           /* number of input (ADC) channels */
#define         CHAN_M1         3           /* CHAN_NUM-1 */
#define         CHAN_P1         5           /* CHAN_NUM+1 */
#define         DELTA_T         0x0E371
#define         LEFT_LIM        128         /* 0.25*SAMP_NUM */
#define         RIGHT_LIM           383         /* (0.75*SAMP_NUM)-1 */
#define         SAMP_NUM        512         /* number of samples */
#define         TRO_PULSE           4           /* 30 msec */
#define         CAL_NUM         60          /* cal/stim samples in buffers */
#define         CAL_NUM_M1          59          /* CAL_NUM-1 */
#define         CAL_ON              39          /* Stim on */
#define         CAL_OFF         19          /* Stim off */
#define         CAL_REP         60          /* cal/stim repetitions for avg */
#define         DELTA_T_FAST        0x0F8DE
#define         SAMP_LIM        200         /* sample time out limit */
#define         SAMP_X2         1024
#define         LOW_BATT        650
#define         E_LOW_BATT          600
#define         H               0
#define         V               1
#define         R               0
#define         I               1

/* Interrupt service function assignments */

#pragma interrupt (nmi_int=31)          /* NMI interrupt */
```

```
    65          #pragma interrupt (extint=29)              /* EXTINT Pin interrupt */
    65          #pragma interrupt (receive=25)             /* Serial Port Receive interrupt */
    65          #pragma interrupt (samp=1)              /* A2D CONVERSION COMPLETE interrupt */
    65          #pragma interrupt (time1=0)             /* TIMER1 OVERFLOW interrupt */
    65
    65
    65          /* Function declarations */
    65
    65          void            main(void);
    66
    66          void            nmi_int(void);          /* Interrupt Service Routines */
    67          void            extint(void);
    68          void            receive(void);
    69          void            time1(void);
    70          void            samp(void);
    71
    71          void            serial(void);
    72          void            senddata(int);
    73          int             recvdata(void);
    74          void            dac(int,int);
    75          void            err(void);
    76          void            fft_for(void);
    77
    77
    77
    77          /* External functions */
    77
    77          extern void         enab_int(void);
    78
    78
    78          /* SFR Images */
    78
    78          unsigned char       im_ioc0, im_ioc1, im_ioc2, im_sp_stat, import1, pmwm;
    79          register unsigned char      status_temp;            /* defined in USER.LIB */
    80
    80
    80
    80          /* Global variables */
    80
    80          register long int       tltemp1, tltemp2, tltemp3, tltemp4, tdenom;
    81          register int        gain_mag, new_pt, alpha1, alpha2, sgv_mag, sgh_mag, tune_pt, temp1_reg,
temp2_reg;
    82          register char           chan, buff_num, buff_not, chan_end;
    83
    83          register int        dv[8];
    84
    84          int             cal_counter, cal_mode, rep_count, cal_monitor, cal_cnt, correct_cnt;
    85          char            timer1_flag, ri_flag, correct_flag, error, loop_flag;
    86          char            restart_flag, tro_counter, rtine_flag;
    87          int             battlevel, battcnt, i_temp;
    88          int                 xreal[512], ximag[512];
    89          long int        lltemp1, lltemp2, lltemp3, lltemp4, denom;
    90          int             out_buffer[2][SAMP_NUM];
    91          int             alpha[SAMP_NUM];
    92          int             eogf[2][2][SAMP_NUM];
    93          int             data_buffer[CHAN_P1][2][SAMP_NUM], batt_volt[3];
    94          int             data_tuner[CHAN_NUM][SAMP_X2];
    95          int             gssum1[CAL_NUM];
```

```
int             gssum2[CAL_NUM];
int             gs[3][2][CAL_NUM];


/* Messages */

const char      mess1[] = " Type ENTER to continue...\n\r";
const char      cls[] = {'\033','[','2','J'};                /* Esc,[,2,J */
const char      bell = '\007';
const char      stim_port[] = {0x02, 0x04, 0x01};       /* i/o lines for stim/cal */


/* Square Root Table */

const int       sqrt[] = { 100, 121, 144, 169, 196, 225, 256, 289,
324, 361, 400, 441, 484, 529, 576, 625, 676, 729, 784, 841, 900,
961, 1024, 1089, 1156, 1225, 1296, 1369, 1444, 1521};


/* Super Gaussian Window, power = 9 */

const int       supgau[] = {16, 20, 26, 32, 40, 49, 61, 74,
90, 108, 129, 154, 182, 214, 251, 293,
339, 391, 449, 514, 585, 662, 747, 840,
940, 1048, 1165, 1289, 1423, 1564, 1714, 1872,
2039, 2213, 2396, 2587, 2785, 2991, 3203, 3422,
3647, 3879, 4115, 4357, 4603, 4853, 5106, 5363,
5622, 5883, 6146, 6409, 6674, 6938, 7202, 7465,
7728, 7988, 8246, 8503, 8756, 9006, 9253, 9497,
9736, 9972, 10203, 10429, 10651, 10869, 11081, 11288,
11490, 11687, 11878, 12065, 12245, 12421, 12591, 12756,
12916, 13070, 13220, 13364, 13503, 13637, 13767, 13891,
14011, 14126, 14237, 14343, 14445, 14543, 14636, 14726,
14812, 14894, 14973, 15048, 15120, 15188, 15253, 15316,
15375, 15431, 15485, 15536, 15585, 15631, 15675, 15717,
15756, 15794, 15829, 15863, 15895, 15925, 15953, 15980,
16006, 16030, 16052, 16074, 16094, 16113, 16131, 16148,
16164, 16179, 16193, 16206, 16218, 16230, 16241, 16251,
16260, 16269, 16278, 16285, 16293, 16300, 16306, 16312,
16317, 16323, 16327, 16332, 16336, 16340, 16343, 16347,
16350, 16353, 16355, 16358, 16360, 16362, 16364, 16366,
16367, 16369, 16370, 16371, 16373, 16374, 16375, 16376,
16376, 16377, 16378, 16378, 16379, 16380, 16380, 16380,
16381, 16381, 16381, 16382, 16382, 16382, 16382, 16383,
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          16384, 16383, 16383, 16383, 16383, 16383, 16383, 16383,
          16383, 16382, 16382, 16382, 16382, 16381, 16381, 16381,
          16380, 16380, 16380, 16379, 16378, 16378, 16377, 16376,
          16376, 16375, 16374, 16373, 16371, 16370, 16369, 16367,
          16366, 16364, 16362, 16360, 16358, 16355, 16353, 16350,
          16347, 16343, 16340, 16336, 16332, 16327, 16323, 16317,
          16312, 16306, 16300, 16293, 16285, 16278, 16269, 16260,
          16251, 16241, 16230, 16218, 16206, 16193, 16179, 16164,
          16148, 16131, 16113, 16094, 16074, 16052, 16030, 16006,
          15980, 15953, 15925, 15895, 15863, 15829, 15794, 15756,
          15717, 15675, 15631, 15585, 15536, 15485, 15431, 15375,
          15316, 15253, 15188, 15120, 15048, 14973, 14894, 14812,
          14726, 14636, 14543, 14445, 14343, 14237, 14126, 14011,
          13891, 13767, 13637, 13503, 13364, 13220, 13070, 12916,
          12756, 12591, 12421, 12245, 12065, 11878, 11687, 11490,
          11288, 11081, 10869, 10651, 10429, 10203, 9972, 9736,
          9497, 9253, 9006, 8756, 8503, 8246, 7988, 7728,
          7465, 7202, 6938, 6674, 6409, 6146, 5883, 5622,
          5363, 5106, 4853, 4603, 4357, 4115, 3879, 3647,
          3422, 3203, 2991, 2785, 2587, 2396, 2213, 2039,
          1872, 1714, 1564, 1423, 1289, 1165, 1048, 940,
          840, 747, 662, 585, 514, 449, 391, 339,
          293, 251, 214, 182, 154, 129, 108, 90,
          74, 61, 49, 40, 32, 26, 20, 16};


          /*===========================================================================*/


          void main(void)
          {
    1         int         i, j, k;
    1
    1     /* System Configuration */
    1
    1         int_mask = 0x00;                        /* mask all interrupts */
    1         imask1 = 0x00;
    1         enab_int();                             /* enable global interrupts */
    1
    1         im_ioc0 = 0x00;                         /* set I/O control registers */
    1         ioc0 = im_ioc0;
    1
    1         im_ioc1 = 0x00;
    1         ioc1 = im_ioc1;
    1
    1         im_ioc2 = 0x00;
    1         ioc2 = im_ioc2;
    1
    1         import1 = 0x00;                 /* initial Port1 config. */
    1         ioport1 = import1;
    1         pmwm = 127;
    1         pwm_control = pmwm;
    1
```

```
  119    1       /* Set up Serial Port */
  119    1
  119    1           im_ioc1 |= 0x21;                /* select TXD on P2.0 */
  120    1           ioc1 = im_ioc1;
  121    1           baud_rate = 0x4D;                   /* baud rate of 9600 on 12 MHz */
  122    1           baud_rate = 0x80;
  123    1           sp_con = 0x09;                  /* Mode 1, enable receive, no parity */
  124    1           wsr = 0x0F;                     /* alternate window */
  125    1           im_sp_stat = 0x20;                  /* set the initial TI bit */
  126    1           status_temp = im_sp_stat;
  127    1           wsr = 0;
  128    1           gain_mag = 1;
  129    1           sgv_mag = 1;
  130    1           sgh_mag = 1;
  131    1           rtine_flag = 0;
  132    1
  132    1           restart_flag = 1;
  133    1
  133    1       /* Initialize flags & pointers */
  133    1
  133    1       restart:
  133    1       /*      if ( restart_flag == 1 ) {*/
  133    1               restart_flag = 0;
  134    1               error = 0;
  135    1               correct_flag = 0;
  136    1               correct_cnt = 2;
  137    1               tro_counter = 0;
  138    1               cal_counter = 0;
  139    1               cal_cnt = 0;
  140    1               cal_monitor = 0;
  141    1               battlevel = 0;
  142    1               battcnt = 0;
  143    1               new_pt = BUFF_START;               /* init. data buffer pointers */
  144    1               tune_pt = 0;
  145    1               buff_num = 0;
  146    1               buff_not = 1;
  147    1
  147    1               for ( i=0; i < 8; i++)
  148    1                   dac( i, 0 );               /* zero DACs */
  149    1
  149    1
  149    1           /* Clear buffers */
  149    1
  149    1               for ( i=0; i < 2; i++) {
  150    2                   for ( j=0; j < SAMP_NUM; j++) {
  151    3                       for ( k=0; k < CHAN_P1; k++)
  152    3                           data_buffer[k][i][j] = 0;
  153    3                       out_buffer[i][j] = 0;          /* zero output buffer */
  154    3                   }
  154    2               }
  154    1               for ( i=0; i<CHAN_NUM; i++ ) {
  155    2                   for ( j=0; j<SAMP_X2; j++ )
  156    2                       data_tuner[i][j] = 0;
  157    2               }
  157    1       /*      }*/
  157    1
  157    1           for ( i_temp=0; i_temp<256; i_temp++ ) {
```

```
2                   for ( j=0; j<8; j++ ) {
3                       dac(j,i_temp-128);
3                       for ( k=0; k<10; k++ )
3                           ;
3                   }
2               }
1
1               for ( i=0; i < 8; i++)
1                   dac( i, 64 );
1
1
1
1           /* Go to main menu */
1
1               serial();
1               loop_flag = 0;
1               ri_flag = 0;
1               ipend1 &= ~0x02;
1
1
1           /* Initialize Timer1 */
1
1               im_ioc1 |= 0x04;                /* enable TIMER1 ovrflow intrpt */
1               ioc1 = im_ioc1;
1
1               timer1_flag = 0;                /* timer1 flag */
1               loop_flag = 0;
1               wsr = 0x0F;                     /* alternate window */
1               timer1 = DELTA_T;                   /* load 7.813 msec timer */
1               wsr = 0;
1
1               int_mask |= 0x03;                   /* unmask TIMER1, A2D DONE, */
1               imask1 |= 0x22;                 /* EXTINT, and RI intrpt */
1
1
1           /* Loop endlessly.............. */
1
1           /* Wait for Timer1 Overflow (every 7.813 msec) to start another sampling
1           sequence.  The TIMER1 interrupt handling routine starts the CHAN_NUM channel
1           sweep: First the last data point is written out to the DAC, then each ADC is
1           sampled on an interrupt driven basis. */
1
1
1           next:
1
1           /* Has the serial port received a character? */
1
1               if ( (ri_flag == 1) | (rtine_flag == 99) ) {
2                   int_mask &= ~0x03;          /* mask TIMER1 & A2D DONE intrpts */
2                   imask1 &= ~0x22;        /* mask EXTINT & RI intrpts */
2                   serial();
2                   loop_flag = 0;
2                   ri_flag = 0;
2                   correct_flag = 0;
2                   correct_cnt = 2;
2                   timer1_flag = 0;
2                   ipend1 &= ~0x02;
```

```
 186    2             wsr = 0x0F;            /* alternate window */
 187    2             timer1 = DELTA_T;
 188    2             wsr = 0;
 189    2             int_mask |= 0x03;          /* unmask TIMER1 & A2D DONE intrpts */
 190    2             imask1 |= 0x22;        /* unmask EXTINT & RI intrpts */
 191    2             goto wait;
 192    2         }
 192    1
 192    1         battlevel = 0;
 193    1         for ( i=0; i<3; i++ ) {
 194    2             if ( batt_volt[i] < LOW_BATT )
 195    2                 battlevel = 300;
 196    2             if ( batt_volt[i] < E_LOW_BATT )
 197    2                 battlevel = 70;
 198    2         }
 198    1
 198    1
 198    1         if ( restart_flag == 1 )
 199    1             goto restart;
 200    1         if ( correct_flag != 1 )
 201    1             goto wait;
 202    1
 202    1
 202    1     /* Load EOG-VU, window the data, multiply by PRE_SCALE, & transform */
 202    1
 202    1         for ( i_temp=0; i_temp < 512; i_temp++ ) {
 203   2          xreal[i_temp] = (int)((((long) data_buffer[2][buff_not][i_temp])*supgau[i_temp])/256);
 204    2             ximag[i_temp] = 0;
 205    2         }
 205    1
 205    1         fft_for();
 206    1         if ( error != 0 ) {
 207    2             err();
 208    2             goto restart;
 209    2         }
 209    1
 209    1     /* Save VU-EOG(w) */
 209    1
 209    1
 209    1         for ( i_temp=0; i_temp < 512; i_temp++ ) {
 210    2             eogf[0][0][i_temp] = (int) (((long) xreal[i_temp] * 10) / PRE_SCALE);
 211    2             eogf[0][1][i_temp] = (int) (((long) ximag[i_temp] * 10) / PRE_SCALE);
 212    2
 212    2
 212    2     /* Load EOG-VL, window the data, multiply by PRE_SCALE, & transform */
 212    2
 212   2          xreal[i_temp] = (int)((((long) data_buffer[3][buff_not][i_temp])*supgau[i_temp])/256);
 213    2             ximag[i_temp] = 0;
 214    2         }
 214    1
 214    1         fft_for();
 215    1         if ( error != 0 ) {
 216    2             err();
 217    2             goto restart;
 218    2         }
 218    1
 218    1
```

```
/* alpha(w) = EOG-VU(w) / EOG-VL(w) ; alpha(w) is scaled by 10 */

    for ( i_temp=0; i_temp < 512; i_temp++ ) {

        xreal[i_temp] = (int) (((long) xreal[i_temp] * 10) / PRE_SCALE);
        ximag[i_temp] = (int) (((long) ximag[i_temp] * 10) / PRE_SCALE);

        lltemp1 = gain_mag * ((eogf[0][0][i_temp] * (long) xreal[i_temp])
             + (eogf[0][1][i_temp] * (long) ximag[i_temp]));
        denom = ( (((long) xreal[i_temp]) * xreal[i_temp]) +
         (((long) ximag[i_temp]) * ximag[i_temp]) ) * 10;

        if ( lltemp1 < 0 )
            lltemp1 = -lltemp1;

        if ( denom == 0 )
            xreal[i_temp] = 40;
        else {
            lltemp2 = lltemp1 / denom;
            if ( lltemp2 > 40 )
                lltemp2 = 40;
            if ( lltemp2 < 10 )
                lltemp2 = 10;
            xreal[i_temp] = (int) lltemp2;
        }
        alpha[i_temp] = xreal[i_temp];
    }




/* Load EOG-H(L-R), window the data, multiply by PRE_SCALE, & transform */

    for ( i_temp=0; i_temp < 512; i_temp++ ) {
     xreal[i_temp] = (int)((((long) data_buffer[1][buff_not][i_temp])*supgau[i_temp])/256);
        ximag[i_temp] = 0;
    }

    fft_for();
    if ( error != 0 ) {
        err();
        goto restart;
    }

    for ( i_temp=0; i_temp < 512; i_temp++ ) {
        eogf[1][0][i_temp] = (int) (((long) xreal[i_temp] * 10) / PRE_SCALE);
        eogf[1][1][i_temp] = (int) (((long) ximag[i_temp] * 10) / PRE_SCALE);
    }



/*----------------------------------------------------------*/

/* Correct the EEG */

    for ( i_temp=0; i_temp < SAMP_NUM; i_temp++ ) {

```

```
 246    2            alpha1 = (alpha[i_temp] + 10)/2;           /* alpha + 1 */
 247    2            alpha2 = (alpha[i_temp] - 10)/2;           /* alpha - 1 */
 248    2
 248    2      /*           (alpha+1)*D1v + (alpha-1)*D2v
 248    2         DSGv(w) = ------------------------------ * SGv(w)
 248    2                   (alpha+1)*D3v + (alpha-1)*D4v
 248    2      */
 248    2
 248    2            lltemp1 = (((long) dv[0])*alpha1) + (((long) dv[1])*alpha2);
 249    2            lltemp2 = (((long) dv[2])*alpha1) + (((long) dv[3])*alpha2);
 250    2            if ( lltemp2 == 0 ) {
 251    3                error = 100;
 252    3                err();
 253    3                goto restart;
 254    3            }
 254    2
 254    2      /*        DSGv(w) * EOGvu(w)          */
 254    2
 254    2            lltemp3 = lltemp1 * eogf[0][0][i_temp];
 255    2            lltemp4 = lltemp1 * eogf[0][1][i_temp];
 256    2
 256    2            xreal[i_temp] = (int) ( (lltemp3 / lltemp2) & 65535 );
 257    2            ximag[i_temp] = (int) ( (lltemp4 / lltemp2) & 65535 );
 258    2
 258    2
 258    2
 258    2      /*           (alpha+1)*D1h + (alpha-1)*D2h
 258    2         DSGh(w) = ------------------------------ * SGh(w)
 258    2                   (alpha+1)*D3h + (alpha-1)*D4h
 258    2      */
 258    2
 258    2            lltemp1 = (((long) dv[4])*alpha1) + (((long) dv[5])*alpha2);
 259    2            lltemp2 = (((long) dv[6])*alpha1) + (((long) dv[7])*alpha2);
 260    2            if ( lltemp2 == 0 ) {
 261    3                error = 101;
 262    3                err();
 263    3                goto restart;
 264    3            }
 264    2
 264    2      /*        DSGh(w) * EOGh(w)          */
 264    2
 264    2            lltemp3 = lltemp1 * eogf[1][0][i_temp];
 265    2            lltemp4 = lltemp1 * eogf[1][1][i_temp];
 266    2
 266    2      /*    (DSGv(w) * EOGvu(w)) + (DSGh(w) * EOGh(w))        */
 266    2
 266    2            xreal[i_temp] += (int) ( (lltemp3 / lltemp2) & 65535 );
 267    2            ximag[i_temp] += (int) ( (lltemp4 / lltemp2) & 65535 );
 268    2
 268    2
 268    2      /* Complex Conjugate */
 268    2
 268    2            ximag[i_temp] = -ximag[i_temp];
 269    2         }
 269    1
 269    1
 269    1      /* Inverse Transform */
```

```

    fft_for();                               /* inverse FFT */
    if ( error != 0 ) {
        err();
        goto restart;
    }

/* Remove Window */

    for ( i_temp=BUFF_START; i_temp < (SAMP_NUM-BUFF_START); i_temp++ ) {
        xreal[i_temp] = (int)(( ((long) xreal[i_temp]) * 83886) / supgau[i_temp]);
    }


/* Moving Average Filter (7 point) of corrector */

    for ( i_temp=BUFF_START; i_temp < (SAMP_NUM-BUFF_START); i_temp++ ) {
       alpha[i_temp] = (xreal[i_temp-3] + xreal[i_temp-2] + xreal[i_temp-1] + xreal[i_temp]
+
                     xreal[i_temp+1] + xreal[i_temp+2] + xreal[i_temp+3]) / 7;
    }


/*      EEGcorr(t) = EEGobs(t) - IFFT( (SGv * EOGvu) + (SGh * EOGh) ) */

    for ( i_temp=BUFF_START; i_temp < (SAMP_NUM-BUFF_START); i_temp++ ) {
        out_buffer[buff_not][i_temp] = data_buffer[0][buff_not][i_temp] - alpha[i_temp];
    }

    correct_flag = 0;

wait:
    loop_flag--;
    while ( timer1_flag == 0)
        ;
    timer1_flag = 0;

/* Loop again */

    goto next;                               /* wait for another TIMER1 INTERRUPT */
}



/*----------------------------------------------------------------------*/
/* nmi_int Function  - NMI interrupt handler  */

void    nmi_int(void)
{
    imask1 = 0x00;                                   /* disable interrupts */
    int_mask = 0x00;
    error = 3;                                       /* error */
    err();
}



```

```
 293
 293          /*-------------------------------------------------------------------*/
 293          /* extint Function  - EXTINT interrupt handler  */
 293          /*                       - senses an external trigger on TRI */
 293
 293          void    extint(void)
 293          {
 294    1         tro_counter = TRO_PULSE;               /* load TRO counter */
 295    1     }
 297
 297
 297
 297
 297
 297          /*-------------------------------------------------------------------*/
 297          /* Receive Function  - Serial Port Receive interrupt handler  */
 297
 297          void    receive(void)
 297          {
 298    1         ri_flag = 1;
 299    1         getchar();
 300    1     }
 302
 302
 302
 302
 302
 302          /*-------------------------------------------------------------------*/
 302          /* TIME1 - TIMER1 overflow interrupt handler
 302                  - Operates in conjunction with SAMP */
 302
 302          void    time1(void)
 302          {
 303    1         int         i, j, k;
 304    1
 304    1     /* Reset TIMER1 */
 304    1
 304    1         if ( rtine_flag != 1 ) {
 305    2             wsr = 0x0F;
 306    2             timer1 = DELTA_T;
 307    2             wsr = 0;
 308    2         }
 308    1         else {
 309    2             wsr = 0x0F;
 310    2             timer1 = DELTA_T_FAST;
 311    2             wsr = 0;
 312    2         }
 312    1
 312    1         if ( (loop_flag > 0) & (rtine_flag != 3) ) {
 313    2             error = 88;
 314    2             err();
 315    2         }
 315    1
 315    1     /* Is TRO high ? */
 315    1
 315    1         if ( tro_counter > 0 )
 316    1             tro_counter--;
 317    1
 317    1         battcnt++;
 318    1         if ( battcnt >= 32000 )
 319    1             battcnt = 0;
 320    1         if ( battlevel != 0 ) {
 321    2             if ( (battcnt % battlevel) == 0 ) {
 322    3                 if ( ((battcnt / battlevel) % 2) == 0 )
 323    3                     pwm_control = pmwm;
 324    3                 else
 325    3                     pwm_control = 0;
 326    3             }
 326    2         }
 326    1
 326    1     /* Interrogate ? */
 326    1
 326    1         if ( rtine_flag == 1) {
 327    2             i = CAL_NUM_M1 - cal_counter;
 328    2             gssum1[i] += data_buffer[((cal_mode%2)/cal_mode)*2][buff_num][new_pt-1];
 329    2             gssum2[i] += data_buffer[(cal_mode%2)+2-(cal_mode/2)][buff_num][new_pt-1];
 330    2
 330    2             if ( cal_counter > CAL_ON ) {
 331    3                 import1 &= ~(stim_port[3-cal_mode]);
 332    3                 ioport1 = import1;
 333    3             }
 333    2             else if (cal_counter > CAL_OFF ) {
 335    3                 import1 |= (stim_port[3-cal_mode]);
 336    3                 ioport1 = import1;
 337    3             }
 337    2             else if (cal_counter >= 0 ) {
 339    3                 import1 &= ~(stim_port[3-cal_mode]);
 340    3                 ioport1 = import1;
 341    3             }
 341    2             cal_counter--;
 342    2
 342    2             if (cal_counter < 0) {
 343    3                 cal_counter = CAL_NUM_M1;
 344    3                 rep_count--;
 345    3
 345    3                 if ( rep_count == 0 ) {
 346    4                     int_mask &= ~0x01;          /* mask TIMER1 intrpt */
 347    4                     cal_mode--;
 348    4                     if ( cal_mode == 0 ) {
 349    5                         rtine_flag = 2;
 350    5                         tune_pt = 0;
 351    5                         new_pt = BUFF_START;
 352    5                         buff_num = 0;
 353    5                         buff_not = 1;
 354    5                     }
 354    4                     rep_count = CAL_REP;        /* reset average counter */
 355    4
 355    4                     for ( i=0; i < CAL_NUM; i++) {              /* average */
 356    5                         gs[2-cal_mode][0][i] = (gssum1[i] / CAL_REP);
 357    5                         gs[2-cal_mode][1][i] = (gssum2[i] / CAL_REP);
 358    5                     }
 358    4                     temp1_reg = (gs[2-cal_mode][0][CAL_NUM_M1] + gs[2-cal_mode][0][0]) / 2;
 359    4                     temp2_reg = (gs[2-cal_mode][1][CAL_NUM_M1] + gs[2-cal_mode][1][0]) / 2;
 360    4                     for ( i=0; i < CAL_NUM; i++) {
```

```
5                       gs[2-cal_mode][0][i] -= temp1_reg;
5                       gs[2-cal_mode][1][i] -= temp2_reg;
5                       gssum1[i] = 0;
5                       gssum2[i] = 0;
5                   }
4               }
3               loop_flag = 0;
3               int_mask |= 0x01;
3               goto skiploop;
3           }
2       }
1
1
1       if ( rtine_flag == 7 ) {
2           if ( cal_cnt > 100 ) {
3               import1 &= ~(stim_port[2]);
3               ioport1 = import1;
3           }
2           else if (cal_cnt > 90 ) {
3               import1 |= (stim_port[2]);
3               ioport1 = import1;
3           }
2           else if (cal_cnt >= 0 ) {
3               import1 &= ~(stim_port[2]);
3               ioport1 = import1;
3           }
2           cal_cnt--;
2
2           if (cal_cnt < 0) {
3               cal_cnt = 150;
3               cal_monitor--;
3               if ( cal_monitor == 0 ) {
4                   int_mask &= ~0x01;
4                   rtine_flag = 0;
4                   printf("\n\r\n\r\n\r       REAL TIME MONITQRING...\n\r\n\r\n\r");
4                   loop_flag = 0;
4                   int_mask |= 0x01;
4                   goto skiploop;
4               }
3           }
2       }
1
1
1   /* Initiate the first A/D Conversion */
1
1       chan = 0;                       /* load ADC chan offset */
1       int_mask |= 0x02;
1       ad_command = CHAN_BASE;             /* start 1st ADC conversion */
1       loop_flag = 2;
1   skiploop:
1       timer1_flag = 1;
1   }




    /*------------------------------------------------------------------------*/
```

```
 398          /* SAMP - A2D CONVERSION COMPLETE interrupt handler.
 398                 - Operates in conjunction with TIME1.
 398                     - The last sample in the data_buffer is written out to the
 398                     corresponding DAC, converted to 8 bits.
 398                 - reads the sample from the ADC.
 398                 - returns a 10 bit value.
 398                 - start a conversion on the next channel of the sweep. */
 398
 398          void    samp(void)
 398
 398          {
 399     1        register int    temp_reg;
 400     1
 400     1    /*      Write out the data to the DAC
 400     1        - convert raw data from 10 bits to 8 bits; */
 400     1
 400     1        if ( chan == 0 ) {
 401     2            dac( 0, (data_buffer[0][buff_num][new_pt-1] >> 2) );
 402     2            if ( rtine_flag == 3 ) {
 403     3                dac( 1, (data_buffer[4][buff_num][new_pt-1] >> 2) );
 404     3                dac( 2, (out_buffer[buff_num][new_pt] >> 2) );
 405     3                dac( 3, (data_buffer[4][buff_num][new_pt] >> 2) );
 406     3                dac( 4, (data_buffer[0][buff_num][new_pt] >> 2) );
 407     3                dac( 5, (data_buffer[1][buff_num][new_pt] >> 2) );
 408     3                dac( 6, (data_buffer[2][buff_num][new_pt] >> 2) );
 409     3                dac( 7, (data_buffer[3][buff_num][new_pt] >> 2) );
 410     3            }
 410     2            else {
 411     3                dac( 1, (data_buffer[1][buff_num][new_pt-1] >> 2) );
 412     3                dac( 2, (data_buffer[2][buff_num][new_pt-1] >> 2) );
 413     3                dac( 3, (data_buffer[3][buff_num][new_pt-1] >> 2) );
 414     3            }
 414     2        }
 414     1
 414     1
 414     1    /* Read a new sample from the ADC; convert from 0 - 1023 to +- 512 */
 414     1
 414     1        if ( chan < 4 ) {
 415     2            temp_reg = ad_result_hi;
 416     2            temp_reg = ((( temp_reg << 8) + ad_result_lo) >> 6) - 512;
 417     2            data_buffer[chan][buff_num][new_pt] = temp_reg;
 418     2        }
 418     1        else if ( chan < 7 ) {
 420     2            temp_reg = ad_result_hi;
 421     2            temp_reg = (( temp_reg << 8) + ad_result_lo) >> 6;
 422     2            batt_volt[chan-4] = temp_reg;
 423     2        }
 423     1        if ( chan == 3 ) {
 424     2            data_buffer[4][buff_num][new_pt] = -200;
 425     2            if ( tro_counter > 0 )
 426     2                data_buffer[4][buff_num][new_pt] = 200;
 427     2        }
 427     1
 427     1    /* If necessary, store it in the other buffer as well */
 427     1
 427     1        if ( (rtine_flag == 2) & (chan < CHAN_NUM) )
 428     1            data_tuner[chan][tune_pt] = data_buffer[chan][buff_num][new_pt];
```

```
429      1          if ( new_pt < LEFT_LIM )
430      1              data_buffer[chan] [buff_not] [new_pt+BUFF_DIFF] = temp_reg;
431      1          else if ( new_pt > RIGHT_LIM )
433      1              data_buffer[chan] [buff_not] [new_pt-BUFF_DIFF] = temp_reg;
434      1
434      1      /* Either start a new conversion, or update the data pointers */
434      1
434      1          chan_end = 8;
435      1          if ( rtine_flag == 1 )
436      1              chan_end = 4;
437      1          chan++;
438      1          if ( chan < chan_end )
439      1              ad_command = CHAN_BASE + chan;            /* start next conversion */
440      1          else {                              /* Update data buffer pointers */
441      2              if ( new_pt < (SAMP_NUM-BUFF_START) ) {
442      3                  new_pt++;
443      3                  tune_pt++;
444      3                  if ( (tune_pt == SAMP_X2) & (rtine_flag == 2) )
445      3                      rtine_flag = 99;
446      3                  if ( rtine_flag == 3 ) {
447      4                      if ( new_pt == 129 ) {
448      5                          if ( correct_flag == 1 ) {
449      6                              error = 80;
450      6                              err();
451      6                          }
451      5                          else {
452      6                              if ( correct_cnt > 0 )
453      6                                  correct_cnt--;
454      6                              if ( correct_cnt == 0 )
455      6                                  correct_flag = 1;
456      6                          }
456      5                      }
456      4                  }
456      3              }
456      2              else {
457      3                  new_pt = BUFF_START;
458      3                  temp_reg = buff_not;
459      3                  buff_not = buff_num;
460      3                  buff_num = temp_reg;
461      3              }
461      2              loop_flag--;
462      2              int_mask &= ~0x02;
463      2          }
463      1
463      1      }
465
465
465
465
465
465             /*-----------------------------------------------------------------------*/
465             /* Serial Port Communications Function    */
465
465
465             void    serial(void)
465             {
466      1          int     resp, i, j, k, resptmp, jk, tempwait;
```

```
1
1
1           int_mask = 0;
1           pwm_control = pmwm;
1           if ( rtine_flag == 98 )
1               goto menuu;
1           if ( rtine_flag == 99 ) {
2                    printf("Press 'PgDn', select '7', and then type 'drive'.\n\rThen type upper case
'A'.\n\r");
2                   printf("Interrogation data will take fifteen minutes to download.\n\r");
2       sndgs:
2                   resp = getchar();
2                   printf("%c",resp);
2                   resp -= 65;
2                   if ( resp != 0 )
2                       goto sndgs;
2                   printf("\n");
2                   for ( i=0; i<3; i++ ) {
3                       for ( j=0; j<2; j++ ) {
4                           for ( k=0; k<CAL_NUM; k++ ) {
5                               senddata(gs[i][j][k]);
5                               for ( jk=0; jk<10000; jk++ )
5                                   tempwait = 0;
5                           }
4                       }
3                   }
2                   for ( i=0; i<CHAN_NUM; i++ ) {
3                       for ( j=0; j<SAMP_X2; j++ ) {
4                           senddata(data_tuner[i][j]);
4                           for ( jk=0; jk<10000; jk++ )
4                               tempwait = 0;
4                       }
3                   }
2
2                   printf("Push 'ESC', ALT-X, 'Y', and then run the program EEG.\n\r");
2                   goto menuu;
2           }
1
1       menu:
1           printf("\n\r\n\r\n\r\n\r\n\r\n\r\n\r\n\r\n\r     GMS Engineering Corporation\n\r");
1           printf("    EEG Artifact Rejection System\n\r\n\r\n\r\n\r\n\r\n\r");
1           printf("        N - Channel Number Selection\n\r");
1           printf("        L - LED Light Level\n\r");
1           printf("        R - Real Time Monitoring\n\r");
1           printf("        P - Calibration Pulses\n\r");
1           printf("        I - Interrogation\n\r");
1           printf("        C - Correction\n\r\n\r\n\r\n\r\n\r\n\r");
1           printf("    Enter RESPONSE > ");
1       menuu:
1           resp = getchar();
1           printf("%c",resp);
1
1           if ( (resp == 'L') | (resp == 'l') ) {
2       lvl4:
2               resptmp = pmwm + 1;
2               printf("\n\rCurrent light level is: %d\n\rEnter new level (1-255) > ",resptmp);
2               resptmp = 0;
2       lvlll:
```

```
2                resp = getchar();
2                printf("%c",resp);
2                if ( resp == 13 )
2                    goto lvll;
2                if ( (resp<48) | (resp>=58) )
2                    goto lvlll;
2                resptmp = (resptmp*10) + (resp-48);
2                goto lvlll;
2        lvll:
2                if ( resptmp > 255 )
2                    goto lvl4;
2                if ( resptmp == 0 )
2                    resptmp = pmwm + 1;
2                resptmp--;
2                pmwm = resptmp;
2                pwm_control = pmwm;
2            }
1
1            else if ( (resp == 'R') | (resp == 'r') ) {
2                printf("\n\r\n\r\n\r       REAL TIME MONITORING...\n\r\n\r\n\r");
2                rtine_flag = 0;
2                goto menu_end;
2            }
1
1            else if ( (resp == 'P') | (resp == 'p') ) {
2                printf("\n\r\n\r\n\r        Calibra+`on Pulses\n\r\n\r\n\r");
2                rtine_flag = 7;
2                cal_monitor = 300;
2                cal_cnt = 150;
2                goto menu_end;
2            }
1
1            else if ( (resp == 'I') | (resp == 'i') ) {
2                cal_counter = CAL_NUM_M1;
2                cal_mode = 3;
2                rep_count = CAL_REP;
2                rtine_flag = 1;
2                for ( i=0; i<CAL_NUM; i++ ) {
3                    gssum1[i] = 0;
3                    gssum2[i] = 0;
3                }
2                printf("\n\r\n\r\n\r       INTERROGATING...\n\r\n\r\n\r");
2                goto menu_end;
2            }
1            else if ( (resp == 'C') | (resp == 'c') ) {
2                printf("\n\r\n\r");
2                printf("Press 'PgUp', select '7', and then type 'correct'.\n\r");
2                sgv_mag = recvdata();
2                sgh_mag = recvdata();
2                gain_mag = recvdata();
2                for ( i=0; i<8; i++ )
2                    dv[i] = recvdata();
2                dv[0] = ((int) (((long) dv[0] * sgv_mag) / 10)) & 65535;
2                dv[4] = ((int) (((long) dv[4] * sgh_mag) / 10)) & 65535;
2                rtine_flag = 3;
2                printf("\n\r\n\r\n\r       CORRECTING...\n\r\n\r\n\r");
2                resp = getchar();
```

```
 560    2             goto menu_end;
 561    2         }
 561    1         else if ( (resp == 'N') | (resp == 'n') ) {
 563    2     chan4:
 563    2             resptmp = (import1 >> 3) + 1;
 564     2               printf("\n\rCurrent channel number is: %d\n\rEnter new channel number (1-24) >
",resptmp);
 565    2             resptmp = 0;
 566    2     channn:
 566    2             resp = getchar();
 567    2             printf("%c",resp);
 568    2             if ( resp == 13 )
 569    2                 goto chann;
 570    2             if ( (resp<48) | (resp>=58) )
 571    2                 goto channn;
 572    2             resptmp = (resptmp*10) + (resp-48);
 573    2             goto channn;
 574    2     chann:
 574    2             if ( resptmp > 24 )
 575    2                 goto chan4;
 576    2             if ( resptmp == 0 )
 577    2                 resptmp = (import1 >> 3) + 1;
 578    2             resptmp--;
 579    2             import1 &= 0x07;
 580    2             import1 |= (resptmp << 3);
 581    2             ioport1 = import1;
 582    2         }
 582    1
 582    1         goto menu;
 583    1
 583    1     menu_end:
 583    1         ;
 583    1     }
 585
 585
 585          /*-----------------------------------------------------------------*/
 585          /*      SENDOUT DATA Function */
 585
 585          void    senddata(data_out)
 585
 585          int         data_out;
 587
 587          {
 587    1         int         i, j, temp_data, temp_sign, data2_out, data_first;
 588    1         char        temp_chr;
 589    1
 589    1         temp_sign = 0;
 590    1         if ( data_out < 0 ) {
 591    2             temp_sign = 1;
 592    2             data_out = -data_out;
 593    2         }
 593    1         data2_out = 0;
 594    1         data_first = data_out;
 595    1         for ( i=4; i>=0; i-- ) {
 596    2             data_first -= data2_out;
 597    2             temp_data = data_first;
 598    2             for ( j=i; j>0; j-- )
 599    2                 temp_data /= 10;
```

```
2               data2_out = temp_data;
2               for ( j=i; j>0; j-- )
2                   data2_out *= 10;
2               printf("%d", temp_data);
2           }
1           printf("%d\n", temp_sign);
1
1       }






        /*------------------------------------------------------------------*/
        /*      RECEIVE DATA Function */

        int     recvdata(void)

        {
1           int         i, j, temp_data, data_in;
1           char        temp_chr;
1
1           temp_data = 0;
1           for ( i=4; i>=0; i-- ) {
2       retry1:
2               temp_chr = getchar();
2               if ( temp_chr == 32 )
2                   temp_chr = 48;
2               if ( (temp_chr < 48) | (temp_chr >= 58) )
2                   goto retry1;
2               data_in = (int) temp_chr - 48;
2               for ( j=0; j<i; j++ )
2                   data_in *= 10;
2               temp_data += data_in;
2           }
1       retry2:
1           temp_chr = getchar();
1               if ( (temp_chr < 48) | (temp_chr > 49) )
1                   goto retry2;
1           if ( temp_chr == 49 )
1               temp_data = -temp_data;
1           return ( temp_data );
1
1       }






        /*------------------------------------------------------------------*/
        /*      DAC Function */

        void    dac(channel, level)

        int         channel, level;

        {
```

```
1          int         dacc;
1
1      /* Decode DAC address */
1
1          if ( channel <= 3 )
1              dacc = 0xE013 + channel;
1          else
1              dacc = 0xE007 + channel;
1
1          if ( (dacc % 2) == 0)
1              dacc -= 2;
1
1      /* Write out the sample to the DAC */
1
1          if ( level > 127 )
1              level = 127;
1          else if ( level < -128 )
1              level = -128;
1
1          memset( dacc, (level+128), 1 );              /* +- 128 into 0 - 256 */
1      }





       /*-------------------------------------------------------------*/
       /*      Error Function */

       void    err(void)
       {
1          int     i;
1
1          int_mask = 0x00;                   /* mask all interrupts */
1          imask1 = 0x02;
1
1          for ( i=0; i < CHAN_NUM; i++) {
2              dac( i, 0 );                   /* zero DACs */
2          }
1          printf(cls);                       /* clear the screen */
1          printf("\n\n\r\t\t\t\t%cERROR\n\n\r",bell);
1          printf("\t\t\t\tNo. %i\n\r",error);
1
1          int_mask &= ~0x03;         /* mask TIMER1 & A2D DONE intrpts */
1          imask1 &= ~0x22;       /* mask EXTINT & RI intrpts */
1          rtine_flag = 98;
1          serial();
1          ri_flag = 0;
1          ipend1 &= ~0x02;
1          int_mask |= 0x03;          /* unmask TIMER1 & A2D DONE intrpts */
1          imask1 |= 0x22;            /* unmask EXTINT & RI intrpts */
1          restart_flag = 1;
1      }
```

```
MODULE INFORMATION:

     CODE AREA SIZE              = 16DFH   5855D
     CONSTANT AREA SIZE          = 080EH   2062D
     DATA AREA SIZE              = 6FDBH  28635D
     STATIC REGS AREA SIZE       = 005AH     90D
     OVERLAYABLE REGS AREA SIZE  = 000AH     10D
     MAXIMUM STACK SIZE          = 0094H    148D

C-96 COMPILATION COMPLETE.      0 WARNINGS,     0 ERRORS
```

```
DOS 3.30 (038-N) MCS-96 MACRO ASSEMBLER, V1.2

SOURCE FILE: FFT_FOR.A96
OBJECT FILE: FFT_FOR.OBJ
CONTROLS SPECIFIED IN INVOCATION COMMAND: <none>

ERR LOC  OBJECT                  LINE       SOURCE STATEMENT
                                    1   FFT_FO  MODULE STACKSIZE(6)
                                    2
                                    3   ;FFT ALGORITHM FROM INTEL APPLICATIONS NOTE, AP-275, BY IRA HORDON
                                    4   ; "EMBEDDED CONTROL APPLICATIONS", INTEL CORP, 1988.
                                    5
    0000                            6   RSEG
                                    7    EXTRN  error
                                    8
    0024                            9   OSEG at 24H
    0024                           10                   TMPR:           dsl             1
    0028                           11                   TMPI:           dsl             1
    002C                           12                   TMPR1:          dsl             1
    0030                           13                   TMPI1:          dsl             1
    0034                           14                   XRTMP:          dsl             1
    0038                           15                   XITMP:          dsl             1
    003C                           16                   WRP:            dsw             1
    003E                           17                   WIP:            dsw             1
    0040                           18                   PWR:            dsw             1
    0042                           19                   IN_CNT:         dsw             1
    0044                           20                   NDIV2:          dsw             1
                                   21
    0046                           22                   KPTR:           dsw             1
    0048                           23                   KN2:            dsw             1
    004A                           24                   N_SUB_K:        dsw             1
    004C                           25                   RK:                     dsw             1
    004E                           26                   RNK:            dsw             1
    0050                           27                   SHFT_CNT:       dsb             1
    0051                           28                   LOOP_CNT:       dsb             1
                                   29
                                   30
    0000                           31   DSEG
                                   32
                                   33   EXTRN   XREAL, XIMAG
                                   34
                                   35                   ; XREAL, XIMAG: Base addresses for 512 16-bit signed
                                   36                  ; entries for real and imaginary numbers, respectively.
                                   37
                                   38   $EJECT
```

```
ERR LOC  OBJECT               LINE        SOURCE STATEMENT
                               39
    0000                       40   CSEG
                               41
                               42    PUBLIC fft_for ; Starting point for FFT algorithm
                               43
                               44   ;                                  ;;;; START FOURIER CALCULATIONS
    0000                       45   FFT_for:                           ;;;; 400 ' INITIALIZATION OF LOOP
    0000 1100           E      46                  clrb    error
                               47
    0002 FC                    48                  clrvt
    0003 B10151                49                  ldb             loop_cnt, #1
    0006 B10850                50                  ldb             shft_cnt, #8
    0009 A1000244              51                  ld              ndiv2, #512
                               52   ;                                  ;;;; 410        K=0
    000D                       53   OUT_LOOP:
    000D 0146                  54                  clr             kptr
                               55   ;                                  ;;;; 420        IF LOOP > EXP THEN 700
    000F 990951                56                  cmpb    loop_cnt, #9     ; 512 = 2^9
    0012 DA0220A3              57  !               bgt             UNWEAVE
                               58
                               59
    0016                       60   MID_LOOP:                          ;;;; 430 INCRNT=0
    0016 0142                  61                  clr             in_cnt
                               62
                               63                                      ;;;; 440 'CALCULATIONS BEGIN HERE
    0018                       64   IN_LOOP:
    0018 65020042              65                  add             in_cnt, #2  ; 450 INCNT=INCNT+1
                               66                                      ;;;; 460 P=BR(INT(K/(2^SHIFT)))
    001C A04640                67                  ld              pwr, kptr
    001F 085040                68                  shr             pwr,shft_cnt  ; Calculate mult factors
    0022 71FE40                69                  andb    pwr, #11111110b
    0025 A341FC0040     R      70                  ld              pwr, brev[pwr]
                               71   ;                                 ;;;; 470 WRP=WR(P) : WIP=WI(P) : KN2=K+N2
    002A A341FC043C     R      72   gw:            ld              wrp, wr[pwr]
    002F A341FE083E     R      73                  ld              wip, wi[pwr]
    0034 44444648              74                  add             kn2, kptr, ndiv2
                               75
                               76           ;; Complex multiplication follows
                               77
                               78   ;                                 ;;;; 480 TMPR=(WRP*XR(KN2)-WIP*XI(KN2))/2
    0038 FE4F4900003C24 E      79   gm:            mul             tmpr, wrp, xreal[kn2]
    003F FE4F4900003E28 E      80                  mul             tmpi, wip, ximag[kn2]
    0046 682A26                81                  sub             tmpr+2, tmpi+2
                               82   ;                                ;;;; 490 TMPI= (WRP*XI(KN2)+WIP*XR(KN2))/2
    0049 FE4F4900003C2C E      83                  mul             tmpr1, wrp, ximag[kn2]
    0050 FE4F4900003E28 E      84                  mul             tmpi, wip, xreal[kn2]
    0057 642E2A                85                  add             tmpi+2, tmpr1+2
```

```
ERR LOC  OBJECT              LINE        SOURCE STATEMENT
                              86
                              87                                  ;; high byte only of a signed multiply
                              88                                  ;; provides an effective divide by two
                              89
    005A DC55                 90                    BVT            ERR1    ; branch on error
                              91
    005C A34700002C      E    92                    ld           tmpr1, xreal[kptr]  ; 500  TMPR1=XR(K)/2
    0061 0A012C               93                    shra    tmpr1, #1             ;       TMPI1=XI(K)/2
    0064 A347000030      E    94                    ld             tmpi1, ximag[kptr]
    0069 0A0130               95                    shra     tmpi1, #1
                              96
                              97   ;                         ;;;; 510 XR(KN2) = TMPR1 = TMPR1 -TMPR
    006C 48262C34             98   gr2:    sub               xrtmp, tmpr1, tmpr+2
    0070 C349000034      E    99                    st             xrtmp, xreal[kn2]
                             100   ;                         ;;;; 520 XI(KN2) = TMPR1 = TMPI1 -TMPI
    0075 482A3038            101   gx2:    sub               xitmp, tmpi1, tmpi+2
    0079 C349000038      E   102                    st             xitmp, ximag[kn2]
                             103   ;                         ;;;; 530 XR(K) = TMPR1 - TMPR
    007E 44262C34            104                    add            xrtmp, tmpr1, tmpr+2
    0082 C347000034      E   105                    st             xrtmp, xreal[kptr]
                             106   ;                         ;;;; 540 XI(K) = TMPI1 + TMPI
    0087 442A3038            107   gx:              add            xitmp, tmpi1, tmpi+2
    008B C347000038      E   108                    st             xitmp, ximag[kptr]
                             109
    0090 DC23                110                    BVT            ERR2    ; Branch on error
                             111
                             112   ;                                              ;;;; 560 K = K + 1
    0092 65020046            113   ik:     add                    kptr, #2
                             114
                             115   ;                         ;;;; 570 IF INCNT < N2 THEN GOTO 450
    0096 884442              116                    cmp            in_cnt, ndiv2
    0099 D602277B            117 !                  blt            IN_LOOP
                             118
                             119   ;                                              ;;;; 580 K = K + N2
    009D 644446              120                    add            kptr, ndiv2
                             121   ;                ;;;; 590 IF K < N1 THEN GOTO 430
    00A0 89FE0346            122                   cmp           kptr, #1022           ;; N1 = 2 *(N-1)
    00A4 D602276E            123 !                  blt            MID_LOOP
                             124
                             125   ;                              ;;;; 600 LOOP = LOOP + 1 : N2 = N2 / 2
    00A8 1751                126                    incb    loop_cnt                ; 605 SHIFT = SHIFT + 1
    00AA 0A0144              127                    shra    ndiv2, #1
    00AD 1550                128                    decb    shft_cnt
                             129   ;                                              ;;;; 610 GOTO 400
    00AF 275C                130                    br             OUT_LOOP
                             131
                             132
    00B1 B10100          E   133   ERR1:   ldb               error, #01               ; overflow error
    00B4 F0                  134                    ret
    00B5 B10200          E   135   ERR2:   ldb               error, #02               ; overflow error
    00B8 F0                  136                    ret
                             137
                             138   $EJECT
```

```
ERR LOC  OBJECT               LINE        SOURCE STATEMENT
                               139
                               140   ;                                ;;;; 700 ' REORDERING STARTS HERE
    00B9                       141   UNWEAVE:
                               142
                               143   ;                                             ;;;; 720 FOR K = 0 TO 511
    00B9 0146                  144                   clr             kptr
    00BB A100044A              145                   ld              n_sub_k, #1024
                               146
    00BF                       147   UN_LOOP:                ;; Bit reversal of the transformed array
                               148
    00BF A347FC004C      R     149                   ld              rk, brev[kptr]
                               150
    00C4 884C46                151                   cmp             kptr, rk
    00C7 D628                  152                   bge             ENDL
                               153
    00C9 A347000024      E     154                   ld              tmpr, xreal[kptr]
    00CE A347000028      E     155                   ld              tmpi, ximag[kptr]
    00D3 A34D00002C      E     156                   ld              tmpr1, xreal[rk]
    00D8 A34D000030      E     157                   ld              tmpi1, ximag[rk]
                               158
    00DD C34D000024      E     159                   st              tmpr, xreal[rk]
    00E2 C34D000028      E     160                   st              tmpi, ximag[rk]
    00E7 C34700002C      E     161                   st              tmpr1, xreal[kptr]
    00EC C347000030      E     162                   st              tmpi1, ximag[kptr]
                               163
                               164   ;                                                 ;; 950 NEXT K
    00F1 65020046              165   ENDL:   add             kptr, #2
    00F5 6902004A              166                   sub             n_sub_k, #2
    00F9 D7C4                  167                   bne             UN_LOOP
                               168
    00FB F0                    169                   RET
                               170
                               171   ;$nolist
    00FC                       172                   CSEG
                               173
    00FC                       174   BREV:
                               175
    00FC 0000000200010003      176   DCW             2*0, 2*256, 2*128, 2*384, 2*64, 2*320
    0108 8001800340004002      177   DCW             2*192, 2*448, 2*32, 2*288, 2*160, 2*416
    0114 C000C002C001C003      178   DCW             2*96, 2*352, 2*224, 2*480, 2*16, 2*272
    0120 20012003A000A002      179   DCW             2*144, 2*400, 2*80, 2*336, 2*208, 2*464
    012C 6000600260016003      180   DCW             2*48, 2*304, 2*176, 2*432, 2*112, 2*368
    0138 E001E00310001002      181   DCW             2*240, 2*496, 2*8, 2*264, 2*136, 2*392
    0144 9000900290019003      182   DCW             2*72, 2*328, 2*200, 2*456, 2*40, 2*296
    0150 50015003D000D002      183   DCW             2*168, 2*424, 2*104, 2*360, 2*232, 2*488
    015C 3000300230013003      184   DCW             2*24, 2*280, 2*152, 2*408, 2*88, 2*344
    0168 B001B00370007002      185   DCW             2*216, 2*472, 2*56, 2*312, 2*184, 2*440
    0174 F000F002F001F003      186   DCW             2*120, 2*376, 2*248, 2*504, 2*4, 2*260
    0180 0801080388008802      187   DCW             2*132, 2*388, 2*68, 2*324, 2*196, 2*452
    018C 4800480248014803      188   DCW             2*36, 2*292, 2*164, 2*420, 2*100, 2*356
    0198 C801C80328002802      189   DCW             2*228, 2*484, 2*20, 2*276, 2*148, 2*404
    01A4 A800A802A801A803      190   DCW             2*84, 2*340, 2*212, 2*468, 2*52, 2*308
    01B0 68016803E800E802      191   DCW             2*180, 2*436, 2*116, 2*372, 2*244, 2*500
    01BC 1800180218011803      192   DCW             2*12, 2*268, 2*140, 2*396, 2*76, 2*332
    01C8 9801980358005802      193   DCW             2*204, 2*460, 2*44, 2*300, 2*172, 2*428
    01D4 D800D802D801D803      194   DCW             2*108, 2*364, 2*236, 2*492, 2*28, 2*284
    01E0 38013803B800B802      195   DCW             2*156, 2*412, 2*92, 2*348, 2*220, 2*476
```

```
ERR LOC  OBJECT                LINE        SOURCE STATEMENT
    01EC 7800780278017803       196    DCW          2*60, 2*316, 2*188, 2*444, 2*124, 2*380
    01F8 F801F80304000402       197    DCW          2*252, 2*508, 2*2, 2*258, 2*130, 2*386
    0204 8400840284018403       198    DCW          2*66, 2*322, 2*194, 2*450, 2*34, 2*290
    0210 44014403C400C402       199    DCW          2*162, 2*418, 2*98, 2*354, 2*226, 2*482
    021C 2400240224012403       200    DCW          2*18, 2*274, 2*146, 2*402, 2*82, 2*338
    0228 A401A40364006402       201    DCW          2*210, 2*466, 2*50, 2*306, 2*178, 2*434
    0234 E400E402E401E403       202    DCW          2*114, 2*370, 2*242, 2*498, 2*10, 2*266
    0240 1401140394009402       203    DCW          2*138, 2*394, 2*74, 2*330, 2*202, 2*458
    024C 5400540254015403       204    DCW          2*42, 2*298, 2*170, 2*426, 2*106, 2*362
    0258 D401D40334003402       205    DCW          2*234, 2*490, 2*26, 2*282, 2*154, 2*410
    0264 B400B402B401B403       206    DCW          2*90, 2*346, 2*218, 2*474, 2*58, 2*314
    0270 74017403F400F402       207    DCW          2*186, 2*442, 2*122, 2*378, 2*250, 2*506
    027C 0C000C020C010C03       208    DCW          2*6, 2*262, 2*134, 2*390, 2*70, 2*326
    0288 8C018C034C004C02       209    DCW          2*198, 2*454, 2*38, 2*294, 2*166, 2*422
    0294 CC00CC02CC01CC03       210    DCW          2*102, 2*358, 2*230, 2*486, 2*22, 2*278
    02A0 2C012C03AC00AC02       211    DCW          2*150, 2*406, 2*86, 2*342, 2*214, 2*470
    02AC 6C006C026C016C03       212    DCW          2*54, 2*310, 2*182, 2*438, 2*118, 2*374
    02B8 EC01EC031C001C02       213    DCW          2*246, 2*502, 2*14, 2*270, 2*142, 2*398
    02C4 9C009C029C019C03       214    DCW          2*78, 2*334, 2*206, 2*462, 2*46, 2*302
    02D0 5C015C03DC00DC02       215    DCW          2*174, 2*430, 2*110, 2*366, 2*238, 2*494
    02DC 3C003C023C013C03       216    DCW          2*30, 2*286, 2*158, 2*414, 2*94, 2*350
    02E8 BC01BC037C007C02       217    DCW          2*222, 2*478, 2*62, 2*318, 2*190, 2*446
    02F4 FC00FC02FC01FC03       218    DCW          2*126, 2*382, 2*254, 2*510, 2*1, 2*257
    0300 0201020382008202       219    DCW          2*129, 2*385, 2*65, 2*321, 2*193, 2*449
    030C 4200420242014203       220    DCW          2*33, 2*289, 2*161, 2*417, 2*97, 2*353
    0318 C201C20322002202       221    DCW          2*225, 2*481, 2*17, 2*273, 2*145, 2*401
    0324 A200A202A201A203       222    DCW          2*81, 2*337, 2*209, 2*465, 2*49, 2*305
    0330 62016203E200E202       223    DCW          2*177, 2*433, 2*113, 2*369, 2*241, 2*497
    033C 1200120212011203       224    DCW          2*9, 2*265, 2*137, 2*393, 2*73, 2*329
    0348 9201920352005202       225    DCW          2*201, 2*457, 2*41, 2*297, 2*169, 2*425
    0354 D200D202D201D203       226    DCW          2*105, 2*361, 2*233, 2*489, 2*25, 2*281
    0360 32013203B200B202       227    DCW          2*153, 2*409, 2*89, 2*345, 2*217, 2*473
    036C 7200720272017203       228    DCW          2*57, 2*313, 2*185, 2*441, 2*121, 2*377
    0378 F201F2030A000A02       229    DCW          2*249, 2*505, 2*5, 2*261, 2*133, 2*389
    0384 8A008A028A018A03       230    DCW          2*69, 2*325, 2*197, 2*453, 2*37, 2*293
    0390 4A014A03CA00CA02       231    DCW          2*165, 2*421, 2*101, 2*357, 2*229, 2*485
    039C 2A002A022A012A03       232    DCW          2*21, 2*277, 2*149, 2*405, 2*85, 2*341
    03A8 AA01AA036A006A02       233    DCW          2*213, 2*469, 2*53, 2*309, 2*181, 2*437
    03B4 EA00EA02EA01EA03       234    DCW          2*117, 2*373, 2*245, 2*501, 2*13, 2*269
    03C0 1A011A039A009A02       235    DCW          2*141, 2*397, 2*77, 2*333, 2*205, 2*461
    03CC 5A005A025A015A03       236    DCW          2*45, 2*301, 2*173, 2*429, 2*109, 2*365
    03D8 DA01DA033A003A02       237    DCW          2*237, 2*493, 2*29, 2*285, 2*157, 2*413
    03E4 BA00BA02BA01BA03       238    DCW          2*93, 2*349, 2*221, 2*477, 2*61, 2*317
    03F0 7A017A03FA00FA02       239    DCW          2*189, 2*445, 2*125, 2*381, 2*253, 2*509
    03FC 0600060206010603       240    DCW          2*3, 2*259, 2*131, 2*387, 2*67, 2*323
    0408 8601860346004602       241    DCW          2*195, 2*451, 2*35, 2*291, 2*163, 2*419
    0414 C600C602C601C603       242    DCW          2*99, 2*355, 2*227, 2*483, 2*19, 2*275
    0420 26012603A600A602       243    DCW          2*147, 2*403, 2*83, 2*339, 2*211, 2*467
    042C 6600660266016603       244    DCW          2*51, 2*307, 2*179, 2*435, 2*115, 2*371
    0438 E601E60316001602       245    DCW          2*243, 2*499, 2*11, 2*267, 2*139, 2*395
    0444 9600960296019603       246    DCW          2*75, 2*331, 2*203, 2*459, 2*43, 2*299
    0450 56015603D600D602       247    DCW          2*171, 2*427, 2*107, 2*363, 2*235, 2*491
    045C 3600360236013603       248    DCW          2*27, 2*283, 2*155, 2*411, 2*91, 2*347
    0468 B601B60376007602       249    DCW          2*219, 2*475, 2*59, 2*315, 2*187, 2*443
    0474 F600F602F601F603       250    DCW          2*123, 2*379, 2*251, 2*507, 2*7, 2*263
    0480 0E010E038E008E02       251    DCW          2*135, 2*391, 2*71, 2*327, 2*199, 2*455
    048C 4E004E024E014E03       252    DCW          2*39, 2*295, 2*167, 2*423, 2*103, 2*359
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ERR LOC  OBJECT               LINE        SOURCE STATEMENT
    0498 CE01CE032E002E02      253   DCW           2*231, 2*487, 2*23, 2*279, 2*151, 2*407
    04A4 AE00AE02AE01AE03      254   DCW           2*87, 2*343, 2*215, 2*471, 2*55, 2*311
    04B0 6E016E03EE00EE02      255   DCW           2*183, 2*439, 2*119, 2*375, 2*247, 2*503
    04BC 1E001E021E011E03      256   DCW           2*15, 2*271, 2*143, 2*399, 2*79, 2*335
    04C8 9E019E035E005E02      257   DCW           2*207, 2*463, 2*47, 2*303, 2*175, 2*431
    04D4 DE00DE02DE01DE03      258   DCW           2*111, 2*367, 2*239, 2*495, 2*31, 2*287
    04E0 3E013E03BE00BE02      259   DCW           2*159, 2*415, 2*95, 2*351, 2*223, 2*479
    04EC 7E007E027E017E03      260   DCW           2*63, 2*319, 2*191, 2*447, 2*127, 2*383
    04F8 FE01FE03              261   DCW           2*255, 2*511
                               262
                               263
    04FC                       264   WR:
                               265
    04FC FF7FFD7FF57FE97F      266   DCW           32767, 32765, 32757, 32745, 32728, 32705
    0508 A67F867F617F377F      267   DCW           32678, 32646, 32609, 32567, 32521, 32469
    0514 9C7E5F7E1D7ED57D      268   DCW           32412, 32351, 32285, 32213, 32137, 32057
    0520 E37C887C297CC57B      269   DCW           31971, 31880, 31785, 31685, 31580, 31470
    052C 7C7A057A89790979      270   DCW           31356, 31237, 31113, 30985, 30852, 30714
    0538 6B77D8764176A575      271   DCW           30571, 30424, 30273, 30117, 29956, 29791
    0544 857307735472 9D71     272   DCW           29621, 29447, 29268, 29085, 28898, 28706
    0550 5E6F966EC96DF86C      273   DCW           28510, 28310, 28105, 27896, 27683, 27466
    055C 6D6A8B69A668BC67      274   DCW           27245, 27019, 26790, 26556, 26319, 26077
    0568 E864EE63F162F061      275   DCW           25832, 25582, 25329, 25072, 24811, 24547
    0574 D75EC75DB35C9C5B      276   DCW           24279, 24007, 23731, 23452, 23170, 22884
    0580 42581D57F555C954      277   DCW           22594, 22301, 22005, 21705, 21403, 21096
    058C 3351FB4FBF4E814D      278   DCW           20787, 20475, 20159, 19841, 19519, 19195
    0598 844969481C47CD45      279   DCW           18868, 18537, 18204, 17869, 17530, 17189
    05A4 CE417340173FB83D      280   DCW           16846, 16499, 16151, 15800, 15446, 15090
    05B0 8C392438BA364D35      281   DCW           14732, 14372, 14010, 13645, 13279, 12910
    05BC FB30872F112E992C      282   DCW           12539, 12167, 11793, 11417, 11039, 10659
    05C8 2628A8262825A623      283   DCW           10278, 9896, 9512, 9126, 8739, 8351
    05D4 1A1F931D0B1C821A      284   DCW           7962, 7571, 7179, 6786, 6393, 5998
    05E0 E2155514C8123A11      285   DCW           5602, 5205, 4808, 4410, 4011, 3612
    05EC 8C0CFB0A6A09D907      286   DCW           3212, 2811, 2410, 2009, 1608, 1206
    05F8 2403920100006EFE      287   DCW           804, 402, 0, -402, -804, -1206
    0604 B8F927F896F605F5      288   DCW           -1608, -2009, -2410, -2811, -3212, -3612
    0610 55F0C6EE38EDABEB      289   DCW           -4011, -4410, -4808, -5205, -5602, -5998
    061C 07E77EE5F5E36DE2      290   DCW           -6393, -6786, -7179, -7571, -7962, -8351
    0628 DDDD5ADCD8DA58D9      291   DCW           -8739, -9126, -9512, -9896, -10278, -10659
    0634 E1D467D3EFD179D0      292   DCW           -11039, -11417, -11793, -12167, -12539, -12910
    0640 21CCB3CA46C9DCC7      293   DCW           -13279, -13645, -14010, -14372, -14732, -15090
    064C AAC348C2E9C08DBF      294   DCW           -15446, -15800, -16151, -16499, -16846, -17189
    0658 86BD33BAE4B897B7      295   DCW           -17530, -17869, -18204, -18537, -18868, -19195
    0664 C1B37FB241B105B0      296   DCW           -19519, -19841, -20159, -20475, -20787, -21096
    0670 65AC37AB0BAAE3A8      297   DCW           -21403, -21705, -22005, -22301, -22594, -22884
    067C 7EA564A44DA339A2      298   DCW           -23170, -23452, -23731, -24007, -24279, -24547
    0688 159F109E0F9D129C      299   DCW           -24811, -25072, -25329, -25582, -25832, -26077
    0694 319944985A977596      300   DCW           -26319, -26556, -26790, -27019, -27245, -27466
    06A0 DD93089337926A91      301   DCW           -27683, -27896, -28105, -28310, -28510, -28706
    06AC 1E8F638EAC8DF98C      302   DCW           -28898, -29085, -29268, -29447, -29621, -29791
    06B8 FC8A5B8ABF892389      303   DCW           -29956, -30117, -30273, -30424, -30571, -30714
    06C4 7C87F7867786FB85      304   DCW           -30852, -30985, -31113, -31237, -31356, -31470
    06D0 A4843B84D7837883      305   DCW           -31580, -31685, -31785, -31880, -31971, -32057
    06DC 77822B82E381A181      306   DCW           -32137, -32213, -32285, -32351, -32412, -32469
    06E8 F780C9809F807A80      307   DCW           -32521, -32567, -32609, -32646, -32678, -32705
    06F4 288017800B800380      308   DCW           -32728, -32745, -32757, -32765, -32767, -32765
    0700 0B80178028803F80      309   DCW           -32757, -32745, -32728, -32705, -32678, -32646
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ERR LOC  OBJECT                LINE        SOURCE STATEMENT
    070C 9F80C980F7802B81       310   DCW          -32609, -32567, -32521, -32469, -32412, -32351
    0718 E3812B827782C782       311   DCW          -32285, -32213, -32137, -32057, -31971, -31880
    0724 D7833B84A4841285       312   DCW          -31785, -31685, -31580, -31470, -31356, -31237
    0730 7786F7867C870688       313   DCW          -31113, -30985, -30852, -30714, -30571, -30424
    073C BF895B8AFC8AA18B       314   DCW          -30273, -30117, -29956, -29791, -29621, -29447
    0748 AC8D638E1E8FDE8F       315   DCW          -29268, -29085, -28898, -28706, -28510, -28310
    0754 37920893DD93B694       316   DCW          -28105, -27896, -27683, -27466, -27245, -27019
    0760 5A9744983199239A       317   DCW          -26790, -26556, -26319, -26077, -25832, -25582
    076C 0F9D109E159F1DA0       318   DCW          -25329, -25072, -24811, -24547, -24279, -24007
    0778 4DA364A47EA59CA6       319   DCW          -23731, -23452, -23170, -22884, -22594, -22301
    0784 0BAA37AB65AC98AD       320   DCW          -22005, -21705, -21403, -21096, -20787, -20475
    0790 41B17FB2C1B305B5       321   DCW          -20159, -19841, -19519, -19195, -18868, -18537
    079C E4B833BA86BBDBBC       322   DCW          -18204, -17869, -17530, -17189, -16846, -16499
    07A8 E9C048C2AAC30EC5       323   DCW          -16151, -15800, -15446, -15090, -14732, -14372
    07B4 46C9B3CA21CC92CD       324   DCW          -14010, -13645, -13279, -12910, -12539, -12167
    07C0 EFD167D3E1D45DD6       325   DCW          -11793, -11417, -11039, -10659, -10278, -9896
    07CC D8DA5ADCDDDD61DF       326   DCW          -9512, -9126, -8739, -8351, -7962, -7571
    07D8 F5E37EE507E792E8       327   DCW          -7179, -6786, -6393, -5998, -5602, -5205
    07E4 38EDC6EE55F0E4F1       328   DCW          -4808, -4410, -4011, -3612, -3212, -2811
    07F0 96F627F8B8F94AFB       329   DCW          -2410, -2009, -1608, -1206, -804, -402
    07FC 000092012403B604       330   DCW          0, 402, 804, 1206, 1608, 2009
    0808 6A09FB0A8C0C1C0E       331   DCW          2410, 2811, 3212, 3612, 4011, 4410
    0814 C8125514E2156E17       332   DCW          4808, 5205, 5602, 5998, 6393, 6786
    0820 0B1C931D1A1F9F20       333   DCW          7179, 7571, 7962, 8351, 8739, 9126
    082C 2825A8262628A329       334   DCW          9512, 9896, 10278, 10659, 11039, 11417
    0838 112E872FFB306E32       335   DCW          11793, 12167, 12539, 12910, 13279, 13645
    0844 BA3624388C39F23A       336   DCW          14010, 14372, 14732, 15090, 15446, 15800
    0850 173F7340CE412543       337   DCW          16151, 16499, 16846, 17189, 17530, 17869
    085C 1C4769488449FB4A       338   DCW          18204, 18537, 18868, 19195, 19519, 19841
    0868 BF4EFB4F33516852       339   DCW          20159, 20475, 20787, 21096, 21403, 21705
    0874 F5551D5742586459       340   DCW          22005, 22301, 22594, 22884, 23170, 23452
    0880 B35CC75DD75EE35F       341   DCW          23731, 24007, 24279, 24547, 24811, 25072
    088C F162EE63E864DD65       342   DCW          25329, 25582, 25832, 26077, 26319, 26556
    0898 A6688B696D6A4A6B       343   DCW          26790, 27019, 27245, 27466, 27683, 27896
    08A4 C96D966E5E6F2270       344   DCW          28105, 28310, 28510, 28706, 28898, 29085
    08B0 54720773B5735F74       345   DCW          29268, 29447, 29621, 29791, 29956, 30117
    08BC 4176D8766B77FA77       346   DCW          30273, 30424, 30571, 30714, 30852, 30985
    08C8 8979057A7C7AEE7A       347   DCW          31113, 31237, 31356, 31470, 31580, 31685
    08D4 297C887CE37C397D       348   DCW          31785, 31880, 31971, 32057, 32137, 32213
    08E0 1D7E5F7E9C7ED57E       349   DCW          32285, 32351, 32412, 32469, 32521, 32567
    08EC 617F867FA67FC17F       350   DCW          32609, 32646, 32678, 32705, 32728, 32745
    08F8 F57FFD7FFF7F           351   DCW          32757, 32765, 32767
                                352
                                353
    08FE                        354   WI:
                                355
    08FE 00006EFEDCFC4AFB       356   DCW          0, -402, -804, -1206, -1608, -2009
    090A 96F605F574F3E4F1       357   DCW          -2410, -2811, -3212, -3612, -4011, -4410
    0916 38EDABEB1EEA92E8       358   DCW          -4808, -5205, -5602, -5998, -6393, -6786
    0922 F5E36DE2E6E061DF       359   DCW          -7179, -7571, -7962, -8351, -8739, -9126
    092E D8DA58D9DAD75DD6       360   DCW          -9512, -9896, -10278, -10659, -11039, -11417
    093A EFD179D005CF92CD       361   DCW          -11793, -12167, -12539, -12910, -13279, -13645
    0946 46C9DCC774C60EC5       362   DCW          -14010, -14372, -14732, -15090, -15446, -15800
    0952 E9C08DBF32BEDBBC       363   DCW          -16151, -16499, -16846, -17189, -17530, -17869
    095E E4B897B74CB605B5       364   DCW          -18204, -18537, -18868, -19195, -19519, -19841
    096A 41B105B0CDAE98AD       365   DCW          -20159, -20475, -20787, -21096, -21403, -21705
    0976 0BAAE3A8BEA79CA6       366   DCW          -22005, -22301, -22594, -22884, -23170, -23452
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ERR LOC  OBJECT                LINE        SOURCE STATEMENT
    0982 4DA339A229A11DA0       367   DCW          -23731, -24007, -24279, -24547, -24811, -25072
    098E 0F9D129C189B239A       368   DCW          -25329, -25582, -25832, -26077, -26319, -26556
    099A 5A9775969395B694       369   DCW          -26790, -27019, -27245, -27466, -27683, -27896
    09A6 37926A91A290DE8F       370   DCW          -28105, -28310, -28510, -28706, -28898, -29085
    09B2 AC8DF98C4B8CA18B       371   DCW          -29268, -29447, -29621, -29791, -29956, -30117
    09BE BF89288995880688       372   DCW          -30273, -30424, -30571, -30714, -30852, -30985
    09CA 7786FB8584851285       373   DCW          -31113, -31237, -31356, -31470, -31580, -31685
    09D6 D78378831D83C782       374   DCW          -31785, -31880, -31971, -32057, -32137, -32213
    09E2 E381A18164812B81       375   DCW          -32285, -32351, -32412, -32469, -32521, -32567
    09EE 9F807A805A803F80       376   DCW          -32609, -32646, -32678, -32705, -32728, -32745
    09FA 0B80038001800380       377   DCW          -32757, -32765, -32767, -32765, -32757, -32745
    0A06 28803F805A807A80       378   DCW          -32728, -32705, -32678, -32646, -32609, -32567
    0A12 F7802B816481A181       379   DCW          -32521, -32469, -32412, -32351, -32285, -32213
    0A1E 7782C7821D837883       380   DCW          -32137, -32057, -31971, -31880, -31785, -31685
    0A2A A48412858485FB85       381   DCW          -31580, -31470, -31356, -31237, -31113, -30985
    0A36 7C87068895882889       382   DCW          -30852, -30714, -30571, -30424, -30273, -30117
    0A42 FC8AA18B4B8CF98C       383   DCW          -29956, -29791, -29621, -29447, -29268, -29085
    0A4E 1E8FDE8FA2906A91       384   DCW          -28898, -28706, -28510, -23310, -28105, -27896
    0A5A DD93B69493957596       385   DCW          -27683, -27466, -27245, -27019, -26790, -26556
    0A66 3199239A189B129C       386   DCW          -26319, -26077, -25832, -25582, -25329, -25072
    0A72 159F1DA029A139A2       387   DCW          -24811, -24547, -24279, -24007, -23731, -23452
    0A7E 7EA59CA6BEA7E3A8       388   DCW          -23170, -22884, -22594, -22301, -22005, -21705
    0A8A 65AC98ADCDAE05B0       389   DCW          -21403, -21096, -20787, -20475, -20159, -19841
    0A96 C1B305B54CB697B7       390   DCW          -19519, -19195, -18868, -18537, -18204, -17869
    0AA2 86BBDBBC32BE8DBF       391   DCW          -17530, -17189, -16846, -16499, -16151, -15800
    0AAE AAC30EC574C6DCC7       392   DCW          -15446, -15090, -14732, -14372, -14010, -13645
    0ABA 21CC92CD05CF79D0       393   DCW          -13279, -12910, -12539, -12167, -11793, -11417
    0AC6 E1D45DD6DAD758D9       394   DCW          -11039, -10659, -10278, -9896, -9512, -9126
    0AD2 DDDD61DFE6E06DE2       395   DCW          -8739, -8351, -7962, -7571, -7179, -6786
    0ADE 07E792E81EEAABEB       396   DCW          -6393, -5998, -5602, -5205, -4808, -4410
    0AEA 55F0E4F174F305F5       397   DCW          -4011, -3612, -3212, -2811, -2410, -2009
    0AF6 B8F94AFBDCFC6EFE       398   DCW          -1608, -1206, -804, -402, 0, 402
    0B02 2403B6044806D907       399   DCW          804, 1206, 1608, 2009, 2410, 2811
    0B0E 8C0C1C0EAB0F3A11       400   DCW          3212, 3612, 4011, 4410, 4808, 5205
    0B1A E2156E17F918821A       401   DCW          5602, 5998, 6393, 6786, 7179, 7571
    0B26 1A1F9F202322A623       402   DCW          7962, 8351, 8739, 9126, 9512, 9896
    0B32 2628A3291F2B992C       403   DCW          10278, 10659, 11039, 11417, 11793, 12167
    0B3E FB306E32DF334D35       404   DCW          12539, 12910, 13279, 13645, 14010, 14372
    0B4A 8C39F23A563CB83D       405   DCW          14732, 15090, 15446, 15800, 16151, 16499
    0B56 CE4125437A44CD45       406   DCW          16846, 17189, 17530, 17869, 18204, 18537
    0B62 B449FB4A3F4C814D       407   DCW          18868, 19195, 19519, 19841, 20159, 20475
    0B6E 335168529B53C954       408   DCW          20787, 21096, 21403, 21705, 22005, 22301
    0B7A 42586459825A9C5B       409   DCW          22594, 22884, 23170, 23452, 23731, 24007
    0B86 D75EE35FEB60F061       410   DCW          24279, 24547, 24811, 25072, 25329, 25582
    0B92 E864DD65CF66BC67       411   DCW          25832, 26077, 26319, 26556, 26790, 27019
    0B9E 6D6A4A6B236CF86C       412   DCW          27245, 27466, 27683, 27896, 28105, 28310
    0BAA 5E6F2270E2709D71       413   DCW          28510, 28706, 28898, 29085, 29268, 29447
    0BB6 B5735F740475A575       414   DCW          29621, 29791, 29956, 30117, 30273, 30424
    0BC2 6B77FA7784780979       415   DCW          30571, 30714, 30852, 30985, 31113, 31237
    0BCE 7C7AEE7A5C7BC57B       416   DCW          31356, 31470, 31580, 31685, 31785, 31880
    0BDA E37C397D897DD57D       417   DCW          31971, 32057, 32137, 32213, 32285, 32351
    0BE6 9C7ED57E097F377F       418   DCW          32412, 32469, 32521, 32567, 32609, 32646
    0BF2 A67FC17FD87FE97F       419   DCW          32678, 32705, 32728, 32745, 32757, 32765
    0BFE FF7FFD7FF57FE97F       420   DCW          32767, 32765, 32757, 32745, 32728, 32705
    0C0A A67F867F617F377F       421   DCW          32678, 32646, 32609, 32567, 32521, 32469
    0C16 9C7E5F7E1D7ED57D       422   DCW          32412, 32351, 32285, 32213, 32137, 32057
    0C22 E37C887C297CC57B       423   DCW          31971, 31880, 31785, 31685, 31580, 31470
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ERR LOC  OBJECT               LINE        SOURCE STATEMENT
    0C2E 7C7A057A89790979      424   DCW          31356, 31237, 31113, 30985, 30852, 30714
    0C3A 6B77D8764176A575      425   DCW          30571, 30424, 30273, 30117, 29956, 29791
    0C46 B573077354729D71      426   DCW          29621, 29447, 29268, 29085, 28898, 28706
    0C52 5E6F966EC96DF86C      427   DCW          28510, 28310, 28105, 27896, 27683, 27466
    0C5E 6D6A8B69A668BC67      428   DCW          27245, 27C19, 26790, 26556, 26319, 26077
    0C6A E864EE63F162F061      429   DCW          25832, 25582, 25329, 25072, 24811, 24547
    0C76 D75EC75DB35C9C5B      430   DCW          24279, 24007, 23731, 23452, 23170, 22884
    0C82 42581D57F555C954      431   DCW          22594, 22301, 22005, 21705, 21403, 21096
    0C8E 3351FB4FBF4E814D      432   DCW          20787, 20475, 20159, 19841, 19519, 19195
    0C9A B34969481C47CD45      433   DCW          18867, 18537, 18204, 17869, 17530, 17189
    0CA6 CE417340173FB83D      434   DCW          16846, 16499, 16151, 15800, 15446, 15090
    0CB2 8C392438BA364D35      435   DCW          14732, 14372, 14010, 13645, 13279, 12910
    0CBE FB30872F112E992C      436   DCW          12539, 12167, 11793, 11417, 11039, 10659
    0CCA 2628A8262825A623      437   DCW          10278, 9896, 9512, 9126, 8739, 8351
    0CD6 1A1F931D0B1C821A      438   DCW          7962, 7571, 7179, 6786, 6393, 5998
    0CE2 E2155514C8123A11      439   DCW          5602, 5205, 4808, 4410, 4011, 3612
    0CEE 8C0CFB0A6A09D907      440   DCW          3212, 2811, 2410, 2009, 1608, 1206
    0CFA 240392010000          441   DCW          804, 402, 0
                               442
    0D00                       443   END
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SYMBOL TABLE LISTING
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 N A M E                          VALUE    ATTRIBUTES

BREV. . . .   . . . . . . . . . . 00FCH   CODE REL WORD
ENDL. . . . . . . . . . . . . . . 00F1H   CODE REL ENTRY
ERR1. . . . . . . . . . . . . . . 00B1H   CODE REL ENTRY
ERR2. . . . . . . . . . . . . . . 00B5H   CODE REL ENTRY
ERROR . . . . . . . . . . . . . . -----   REG EXTERNAL
FFT_FO. . . . . . . . . . . . . . -----   MODULE STACKSIZE(6)
FFT_FOR . . . . . . . . . . . . . 0000H   CODE REL PUBLIC ENTRY
GM. . . . . . . . . . . . . . . . 0038H   CODE REL ENTRY
GR2 . . . . . . . . . . . . . . . 006CH   CODE REL ENTRY
GW. . . . . . . . . . . . . . . . 002AH   CODE REL ENTRY
GX. . . . . . . . . . . . . . . . 0087H   CODE REL ENTRY
GX2 . . . . . . . . . . . . . . . 0075H   CODE REL ENTRY
IK. . . . . . . . . . . . . . . . 0092H   CODE REL ENTRY
IN_CNT. . . . . . . . . . . . . . 0042H   OVERLAY ABS WORD
IN_LOOP . . . . . . . . . . . . . 0018H   CODE REL ENTRY
KN2 . . . . . . . . . . . . . . . 0048H   OVERLAY ABS WORD
KPTR. . . . . . . . . . . . . . . 0046H   OVERLAY ABS WORD
LOOP_CNT. . . . . . . . . . . . . 0051H   OVERLAY ABS BYTE
MID_LOOP. . . . . . . . . . . . . 0016H   CODE REL ENTRY
N_SUB_K . . . . . . . . . . . . . 004AH   OVERLAY ABS WORD
NDIV2 . . . . . . . . . . . . . . 0044H   OVERLAY ABS WORD
OUT_LOOP. . . . . . . . . . . . . 000DH   CODE REL ENTRY
PWR . . . . . . . . . . . . . . . 0040H   OVERLAY ABS WORD
RK. . . . . . . . . . . . . . . . 004CH   OVERLAY ABS WORD
RNK . . . . . . . . . . . . . . . 004EH   OVERLAY ABS WORD
SHFT_CNT. . . . . . . . . . . . . 0050H   OVERLAY ABS BYTE
TMPI. . . . . . . . . . . . . . . 0028H   OVERLAY ABS LONG
TMPI1 . . . . . . . . . . . . . . 0030H   OVERLAY ABS LONG
TMPR. . . . . . . . . . . . . . . 0024H   OVERLAY ABS LONG
TMPR1 . . . . . . . . . . . . . . 002CH   OVERLAY ABS LONG
UN_LOOP . . . . . . . . . . . . . 00BFH   CODE REL ENTRY
UNWEAVE . . . . . . . . . . . . . 00B9H   CODE REL ENTRY
WI. . . . . . . . . . . . . . . . 08FEH   CODE REL WORD
WIP . . . . . . . . . . . . . . . 003EH   OVERLAY ABS WORD
WR. . . . . . . . . . . . . . . . 04FCH   CODE REL WORD
WRP . . . . . . . . . . . . . . . 003CH   OVERLAY ABS WORD
XIMAG . . . . . . . . . . . . . . -----   DATA EXTERNAL
XITMP . . . . . . . . . . . . . . 0038H   OVERLAY ABS LONG
XREAL . . . . . . . . . . . . . . -----   DATA EXTERNAL
XRTMP . . . . . . . . . . . . . . 0034H   OVERLAY ABS LONG

ASSEMBLY COMPLETED,    NO ERROR(S) FOUND.
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DOS 3.30 (038-N) MCS-96 MACRO ASSEMBLER, V1.2

SOURCE FILE: E_INT.A96
OBJECT FILE: E_INT.OBJ
CONTROLS SPECIFIED IN INVOCATION COMMAND: <none>

ERR LOC  OBJECT                    LINE        SOURCE STATEMENT
                                      1   $PAGELENGTH(51)
                                      2   $TITLE(" ENABLE 80C196 GLOBAL INTERRUPTS")
                                      3
                                      4   E_INT           MODULE  STACKSIZE(12)
                                      5                           PUBLIC  ENAB_INT
                                      6
                                      7   ;       E_INT.A96
                                      8   ;
                                      9   ;       Version 1.0           July 26, 1989
                                     10   ;
                                     11   ;       Jeffrey C. Sigl
                                     12   ;
                                     13   ;       GMS Engineering Corporation
                                     14   ;       8940-D Route 108
                                     15   ;       Columbia, Maryland  21045
                                     16   ;
                                     17   ;
                                     18   ; ==============================================================
                                     19   ;
                                     20   ;       COMMON DEFINITIONS
                                     21
                                     22   $INCLUDE(8096.INC)             ;80C196 REGISTER DEFINITIONS
                                                                                 = 1                2 3
;*******************************************************************************
                               =1    24   ;
                               =1    25   ; 8096.INC - DEFINITION OF SYMBOLIC NAMES FOR THE I/O REGISTERS OF THE
                               =1    26   ;             8096 AND THE 80C196
                               =1    27   ;             (C) INTEL CORPORATION 1983
                                                                                 = 1                2 8
;*******************************************************************************
                               =1    29   ;
                               =1    30   ;/*
                               =1    31   ; *     8096 SFR's
                               =1    32   ; */
    0000                       =1    33   R0            EQU    00H:WORD      ; R    ZERO REGISTER
    0002                       =1    34   AD_COMMAND    EQU    02H:BYTE      ;   W
    0002                       =1    35   AD_RESULT_LO  EQU    02H:BYTE      ; R
    0003                       =1    36   AD_RESULT_HI  EQU    03H:BYTE      ; R
    0003                       =1    37   HSI_MODE      EQU    03H:BYTE      ;   W
    0004                       =1    38   HSO_TIME      EQU    04H:WORD      ;   W
    0004                       =1    39   HSI_TIME      EQU    04H:WORD      ; R
    0006                       =1    40   HSO_COMMAND   EQU    06H:BYTE      ;   W
    0006                       =1    41   HSI_STATUS    EQU    06H:BYTE      ; R
    0007                       =1    42   SBUF          EQU    07H:BYTE      ; R/W
```

```
ERR LOC  OBJECT          LINE       SOURCE STATEMENT
     0008            =1   43   INT_MASK       EQU    08H:BYTE       ; R/W
     0009            =1   44   INT_PENDING    EQU    09H:BYTE       ; R/W
     000A            =1   45   WATCHDOG       EQU    0AH:BYTE       ;   W  WATCHDOG TIMER
     000A            =1   46   TIMER1         EQU    0AH:WORD       ; R
     000C            =1   47   TIMER2         EQU    0CH:WORD       ; R
     000E            =1   48   BAUD_RATE      EQU    0EH:BYTE       ;   W
     000E            =1   49   IOPORT0        EQU    0EH:BYTE       ; R
     000F            =1   50   IOPORT1        EQU    0FH:BYTE       ; R/W
     0010            =1   51   IOPORT2        EQU    10H:BYTE       ; R/W
     0011            =1   52   SP_CON         EQU    11H:BYTE       ;   W
     0011            =1   53   SP_STAT        EQU    11H:BYTE       ; R
     0015            =1   54   IOC0           EQU    15H:BYTE       ;   W
     0015            =1   55   IOS0           EQU    15H:BYTE       ; R
     0016            =1   56   IOC1           EQU    16H:BYTE       ;   W
     0016            =1   57   IOS1           EQU    16H:BYTE       ; R
     0017            =1   58   PWM_CONTROL    EQU    17H:BYTE       ;   W
     0018            =1   59   SP             EQU    18H:WORD       ; R/W
                     =1   60   ;
                     =1   61   ;/*
                     =1   62   ; *     80C196 SFR's
                     =1   63   ; */
     000B            =1   64   IOC2           EQU    0BH:BYTE       ;   W
                     =1   65   ;TIMER2        EQU    0CH:WORD       ; R/W
     0012            =1   66   IPEND1         EQU    12H:BYTE       ; R/W
     0013            =1   67   IMASK1         EQU    13H:BYTE       ; R/W
     0014            =1   68   WSR            EQU    14H:BYTE       ; R/W
     0017            =1   69   IOS2           EQU    17H:BYTE       ; R
                          70
                          71   ; ============================================================
                          72   ;
                          73   ;       CODE SEGMENT
                          74
   0000                   75                  CSEG
                          76
   0000                   77   ENAB_INT:
                          78
   0000 FB                79                  EI                                       ;ENABLE
INTRPTS
   0001 F0                80                  RET
   0002                   81                  END
```

```
SYMBOL TABLE LISTING
------------------

 N A M E                         VALUE    ATTRIBUTES

AD_COMMAND. . . . . . . . . . . .  0002H   NULL ABS BYTE
AD_RESULT_HI. . . . . . . . . . .  0003H   NULL ABS BYTE
AD_RESULT_LO. . . . . . . . . . .  0002H   NULL ABS BYTE
BAUD_RATE . . . . . . . . . . . .  000EH   NULL ABS BYTE
E_INT . . . . . . . . . . . . . .  -----   MODULE STACKSIZE(12)
ENAB_INT. . . . . . . . . . . . .  0000H   CODE REL PUBLIC ENTRY
HSI_MODE. . . . . . . . . . . . .  0003H   NULL ABS BYTE
HSI_STATUS. . . . . . . . . . . .  0006H   NULL ABS BYTE
HSI_TIME. . . . . . . . . . . . .  0004H   NULL ABS WORD
HSO_COMMAND . . . . . . . . . . .  0006H   NULL ABS BYTE
HSO_TIME. . . . . . . . . . . . .  0004H   NULL ABS WORD
IMASK1. . . . .  . . . . . . . .   0013H   NULL ABS BYTE
INT_MASK. . . . . . . . . . . . .  0008H   NULL ABS BYTE
INT_PENDING . . . . . . . . . . .  0009H   NULL ABS BYTE
IOC0. . . . . . . . . . . . . . .  0015H   NULL ABS BYTE
IOC1. . . . . . . . . . . . . . .  0016H   NULL ABS BYTE
IOC2. . . . . . . . . . . . . . .  000BH   NULL ABS BYTE
IOPORT0 . . . . . . . . . . . . .  000EH   NULL ABS BYTE
IOPORT1 . . . . . . . . . . . . .  000FH   NULL ABS BYTE
IOPORT2 . . . . . . . . . . . . .  0010H   NULL ABS BYTE
IOS0. . . . . . . . . . . . . . .  0015H   NULL ABS BYTE
IOS1. . . . . . . . . . . . . . .  0016H   NULL ABS BYTE
IOS2. . . . . . . . . . . . . . .  0017H   NULL ABS BYTE
IPEND1. . . . . . . . . . . . . .  0012H   NULL ABS BYTE
PWM_CONTROL . . . . . . . . . . .  0017H   NULL ABS BYTE
R0. . . . . . . . . . . . . . . .  0000H   NULL ABS WORD
SBUF. . . . . . . . . . . . . . .  0007H   NULL ABS BYTE
SP. . . . . . . . . . . . . . . .  0018H   NULL ABS WORD
SP_CON. . . . . . . . . . . . . .  0011H   NULL ABS BYTE
SP_STAT . . . . . . . . . . . . .  0011H   NULL ABS BYTE
TIMER1. . . . . . . . . . . . . .  000AH   NULL ABS WORD
TIMER2. . . . . . . . . . . . . .  000CH   NULL ABS WORD
WATCHDOG. . . . . . . . . . . . .  000AH   NULL ABS BYTE
WSR . . . . . . . . . . . . . . .  0014H   NULL ABS BYTE

ASSEMBLY COMPLETED,   NO ERROR(S) FOUND.
```

```
MCS-96 MACRO ASSEMBLER    STATUS                                              04/06/90 16:16:41 PAGE     1

DOS 3.30 (038-N) MCS-96 MACRO ASSEMBLER, V1.2

SOURCE FILE: STATUS.A96
OBJECT FILE: STATUS.OBJ
CONTROLS SPECIFIED IN INVOCATION COMMAND: <none>

ERR LOC  OBJECT                LINE        SOURCE STATEMENT
                                  1   public                  status_temp
    0000                          2                                   rseg
    0000                          3   status_temp:    DSB     1               ;Global status register
    0001                          4                                   end


SYMBOL TABLE LISTING
--------------------

 N A M E                          VALUE    ATTRIBUTES

STATUS_TEMP . . . . . . . . . .   0000H   REG REL PUBLIC BYTE

ASSEMBLY COMPLETED,   NO ERROR(S) FOUND.
```

```
MCS-96 MACRO ASSEMBLER    GETCHAR                                    04/06/90 16:16:49 PAGE     1

DOS 3.30 (038-N) MCS-96 MACRO ASSEMBLER, V1.2

SOURCE FILE: GETCHAR.A96
OBJECT FILE: GETCHAR.OBJ
CONTROLS SPECIFIED IN INVOCATION COMMAND: <none>

ERR LOC  OBJECT                  LINE       SOURCE STATEMENT
                                    1   $debug
                                    2   $nolist include (8096.inc)
                                   51
      001C                         52   tmp0     equu          1CH:word
      0006                         53   RI_pos   equ           06H:byte
      00BF                         54   RI_mask equ            0BFH:byte
                                   55
                                   56   extrn    status_temp
                                   57   public   getchar
                                   58
    0000                           59                 CSEG
                                   60
    0000 901100             E      61   getchar:      orb              status_temp, SP_STAT
    0003 3600FA             E      62                        jbc              status_temp, RI_pos, getchar
    0006 B0071C                    63                        ldb              tmp0, sbuf
    0009 71BF00             E      64                        andb     status_temp, #RI_mask
    000C F0                        65                        ret
    000D                           66                        end
```

```
SYMBOL TABLE LISTING
--------------------

 N A M E                          VALUE    ATTRIBUTES

AD_COMMAND. . . . . . . . . . .   0002H   NULL ABS BYTE
AD_RESULT_HI. . . . . . . . . .   0003H   NULL ABS BYTE
AD_RESULT_LO. . . . . . . . . .   0002H   NULL ABS BYTE
BAUD_RATE . . . . . . . . . . .   000EH   NULL ABS BYTE
GETCHAR . . . . . . . . . . . .   0000H   CODE REL PUBLIC ENTRY
HSI_MODE. . . . . . . . . . . .   0003H   NULL ABS BYTE
HSI_STATUS. . . . . . . . . . .   0006H   NULL ABS BYTE
HSI_TIME. . . . . . . . . . . .   0004H   NULL ABS WORD
HSO_COMMAND . . . . . . . . . .   0006H   NULL ABS BYTE
HSO_TIME. . . . . . . . . . . .   0004H   NULL ABS WORD
IMASK1. . . . . . . . . . . . .   0013H   NULL ABS BYTE
INT_MASK. . . . . . . . . . . .   0008H   NULL ABS BYTE
INT_PENDING . . . . . . . . . .   0009H   NULL ABS BYTE
IOC0. . . . . . . . . . . . . .   0015H   NULL ABS BYTE
IOC1. . . . . . . . . . . . . .   0016H   NULL ABS BYTE
IOC2. . . . . . . . . . . . . .   000BH   NULL ABS BYTE
IOPORT0 . . . . . . . . . . . .   000EH   NULL ABS BYTE
IOPORT1 . . . . . . . . . . . .   000FH   NULL ABS BYTE
IOPORT2 . . . . . . . . . . . .   0010H   NULL ABS BYTE
IOS0. . . . . . . . . . . . . .   0015H   NULL ABS BYTE
IOS1. . . . . . . . . . . . . .   0016H   NULL ABS BYTE
IOS2. . . . . . . . . . . . . .   0017H   NULL ABS BYTE
IPEND1. . . . . . . . . . . . .   0012H   NULL ABS BYTE
PWM_CONTROL . . . . . . . . . .   0017H   NULL ABS BYTE
R0. . . . . . . . . . . . . . .   0000H   NULL ABS WORD
RI_MASK . . . . . . . . . . . .   00BFH   NULL ABS BYTE
RI_POS. . . . . . . . . . . . .   0006H   NULL ABS BYTE
SBUF. . . . . . . . . . . . . .   0007H   NULL ABS BYTE
      . . . . . . . . . . . . .   0018H   NULL ABS WORD
      . . . . . . . . . . . . .   0011H   NULL ABS BYTE
SF_     . . . . . . . . . . . .   0011H   NULL ABS BYTE
STATU    MP . . . . . . . . . .   -----   NULL EXTERNAL
TIMER1.   . . . . . . . . . . .   000AH   NULL ABS WORD
TIMER2. .     . . . . . . . . .   000CH   NULL ABS WORD
TMP0. . . . . . . . . . . . . .   001CH   NULL ABS WORD
WATCHDOG. . . . . . . . . . . .   000AH   NULL ABS BYTE
WSR . . . . . . . . . . . . . .   0014H   NULL ABS BYTE

ASSEMBLY COMPLETED,   NO ERROR(S) FOUND.
```

```
MCS-96 MACRO ASSEMBLER    PUTCHAR                                      04/06/90 16:17:22 PAGE    1

DOS 3.30 (038-N) MCS-96 MACRO ASSEMBLER, V1.2

SOURCE FILE: PUTCHAR.A96
OBJECT FILE: PUTCHAR.OBJ
CONTROLS SPECIFIED IN INVOCATION COMMAND: <none>

ERR LOC  OBJECT                LINE       SOURCE STATEMENT
                                  1   $debug
                                  2   $nolist include (8096.inc)
                                 51
      0005                       52   TI_pos  equ          05H:byte
      00DF                       53   TI_mask equu         0DFH:byte
                                 54
                                 55   extrn   status_temp
                                 56   public  putchar
                                 57
    0000                         58                CSEG
                                 59
    0000 901100          E       60   putchar:     orb          status_temp, SP_STAT
    0003 3500FA          E       61                      jbc          status_temp, TI_pos, putchar
    0006 B3180207                62                      ldb          sbuf, 2[sp]
    000A 71DF00          E       63                      andb   status_temp, #TI_mask
    000D F0                      64                      ret
    000E                         65                      end
```

```
SYMBOL TABLE LISTING
--------------------

 N A M E                           VALUE    ATTRIBUTES

AD_COMMAND. . . . . . . . . . .    0002H   NULL ABS BYTE
AD_RESULT_HI. . . . . . . . . .    0003H   NULL ABS BYTE
AD_RESULT_LO. . . . . . . . . .    0002H   NULL ABS BYTE
BAUD_RATE . . . . . . . . . . .    000EH   NULL ABS BYTE
HSI_MODE. . . . . . . . . . . .    0003H   NULL ABS BYTE
HSI_STATUS. . . . . . . . . . .    0006H   NULL ABS BYTE
HSI_TIME. . . . . . . . . . . .    0004H   NULL ABS WORD
HSO_COMMAND . . . . . . . . . .    0006H   NULL ABS BYTE
HSO_TIME. . . . . . . . . . . .    0004H   NULL ABS WORD
IMASK1. . . . . . . . . . . . .    0013H   NULL ABS BYTE
INT_MASK. . . . . . . . . . . .    0008H   NULL ABS BYTE
INT_PENDING . . . . . . . . . .    0009H   NULL ABS BYTE
IOC0. . . . . . . . . . . . . .    0015H   NULL ABS BYTE
IOC1. . . . . . . . . . . . . .    0016H   NULL ABS BYTE
IOC2. . . . . . . . . . . . . .    000BH   NULL ABS BYTE
IOPORT0 . . . . . . . . . . . .    000EH   NULL ABS BYTE
IOPORT1 . . . . . . . . . . . .    000FH   NULL ABS BYTE
IOPORT2 . . . . . . . . . . . .    0010H   NULL ABS BYTE
IOS0. . . . . . . . . . . . . .    0015H   NULL ABS BYTE
IOS1. . . . . . . . . . . . . .    0016H   NULL ABS BYTE
IOS2. . . . . . . . . . . . . .    0017H   NULL ABS BYTE
IPEND1. . . . . . . . . . . . .    0012H   NULL ABS BYTE
PUTCHAR . . . . . . . . . . . .    0000H   CODE REL PUBLIC ENTRY
PWM_CONTROL . . . . . . . . . .    0017H   NULL ABS BYTE
R0. . . . . . . . . . . . . . .    0000H   NULL ABS WORD
SBUF. . . . . . . . . . . . . .    0007H   NULL ABS BYTE
SP. . . . . . . . . . . . . . .    0018H   NULL ABS WORD
SP_CON. . . . . . . . . . . . .    0011H   NULL ABS BYTE
SP_STAT . . . . . . . . . . . .    0011H   NULL ABS BYTE
STATUS_TEMP . . . . . . . . . .    -----   NULL EXTERNAL
TI_MASK . . . . . . . . . . . .    CODFH   NULL ABS BYTE
TI_POS. . . . . . . . . . . . .    0005H   NULL ABS BYTE
TIMER1. . . . . . . . . . . . .    000AH   NULL ABS WORD
TIMER2. . . . . . . . . . . . .    000CH   NULL ABS WORD
WATCHDOG. . . . . . . . . . . .    000AH   NULL ABS BYTE
WSR . . . . . . . . . . . . . .    0014H   NULL ABS BYTE

ASSEMBLY COMPLETED,   NO ERROR(S) FOUND.
```

APPENDIX B: PC SOFTWARE LISTING

```
$declare
c       shell.for

c       Driver for the EEG artifact correction system.


c       Created:December 19, 1989
c       Last Update:     February 14, 1989

c       Steven M. Falk
c       Jeffrey C. Sigl
c       GMS Engineering Corporation
c       8940-D Route 108
c       Columbia, MD  21045
c       (301) 995-0508

        program shell

c Data Structures

        character*6      word
        character*1      chr(6), cls(4), capps, cappi, cr, cappr, cappz
        character*1      bell, resp
        integer          i, j
        integer*4        tmpvb, tmpvbb, tmpva
        integer          step, iresp, ichanl, ichann
        real*4           d1v, d2v, d1h, d2h
        real*4           d3v, d4v, d3h, d4h
        real*4           vmag, hmag, gain, ccmax
        real*4           tmpvbl(11)

c Functions

        integer          ichar
        integer*4        int4

c Data Relations

        equivalence      (word,chr)

c Data Initialization

        data word /6H      /
        data capps, cappi, cappr, cappz /'S', 'I', 'R', 'A'/
        data ichanl, ichann /1, 0/
        cls(1) = 8#33
        cls(2) = 8#133
        cls(3) = 8#62
        cls(4) = 8#112
        bell = 8#7

        step = 0

        d1v = 0.
        d2v = 0.
        d1h = 0.
        d2h = 0.
        d3v = 0.
        d4v = 0.
        d3h = 0.
        d4h = 0.


c Clear the screen

2       write(*,3)(cls(i),i=1,4)
3       format(' ',4a1)

        open(11,file='drive',status='old')
66      read(11,67)resp
67      format(a1)
        if ( resp .ne. cappz ) then
                goto 66
        endif

        call dcalc(cls,d1v,d2v,d1h,d2h,d3v,d4v,d3h,d4h,step,bell,ccmax)

        call sgm(vmag,0)
        call sgm(hmag,1)
        call sgm(gain,2)

        call ftune(d1v,d2v,d1h,d2h,d3v,d4v,d3h,d4h,vmag,hmag,gain,ccmax)

        close(11)

        if ( gain .eq. -9999. ) then
                goto 1357
        endif

        open(12,file='correct',status='new')

        tmpvbl(1) = vmag
        tmpvbl(2) = hmag
        tmpvbl(3) = gain
        tmpvbl(4) = d1v
        tmpvbl(5) = d2v
        tmpvbl(6) = d3v
        tmpvbl(7) = d4v
        tmpvbl(8) = d1h
        tmpvbl(9) = d2h
        tmpvbl(10) = d3h
        tmpvbl(11) = d4h
        do 152 i=1,11
                tmpva = int4(tmpvbl(i))
                tmpvb = tmpva * 10
                if ( tmpva .lt. 0 ) then
                        tmpvb =  tmpvb
                        tmpvb = tmpvb + 1
                endif
                write(12,154)tmpvb
154             format(i6)
152     continue
```

```
  Line#  Source Line        Microsoft FORTRAN Optimizing Compiler Version 4.00

    113
    114           close(12)
    115
    116           write(*,1356)
    117   1356    format(' Correction Matrix now computed for the selected channel.'
    118          + /' EARS Correction opotion can now be run (main menu option C).'
    119
    120   1357    continue
    121
    122           stop
    123           end
```

```
main  Local Symbols

Name                          Class    Type              Size   Offset

D4H . . . . . . . . . . . . . local    REAL*4               4    0002
IRESP . . . . . . . . . . . . local    INTEGER*4            4    0006
TMPVA . . . . . . . . . . . . local    INTEGER*4            4    000a
WORD. . . . . . . . . . . . . local    CHAR*6               6    000c
TMPVB . . . . . . . . . . . . local    INTEGER*4            4    000e
CAPPS . . . . . . . . . . . . local    CHAR*1               1    0012
I . . . . . . . . . . . . . . local    INTEGER*4            4    0012
CAPPI . . . . . . . . . . . . local    CHAR*1               1    0013
CAPPR . . . . . . . . . . . . local    CHAR*1               1    0014
CAPPZ . . . . . . . . . . . . local    CHAR*1               1    0015
J . . . . . . . . . . . . . . local    INTEGER*4            4    0016
ICHANL. . . . . . . . . . . . local    INTEGER*4            4    0016
ICHANN. . . . . . . . . . . . local    INTEGER*4            4    001a
D1V . . . . . . . . . . . . . local    REAL*4               4    001a
TMPVBB. . . . . . . . . . . . local    INTEGER*4            4    001e
D2V . . . . . . . . . . . . . local    REAL*4               4    0022
D3V . . . . . . . . . . . . . local    REAL*4               4    0026
D4V . . . . . . . . . . . . . local    REAL*4               4    002a
TMPVBL. . . . . . . . . . . . local    REAL*4              44    002e
CR. . . . . . . . . . . . . . local    CHAR*1               1    005a
HMAG. . . . . . . . . . . . . local    REAL*4               4    005c
GAIN. . . . . . . . . . . . . local    REAL*4               4    0060
BELL. . . . . . . . . . . . . local    CHAR*1               1    0064
CLS . . . . . . . . . . . . . local    CHAR*1               4    0066
ICHAR . . . . . . . . . . . . local    INTEGER*4            4    006a
VMAG. . . . . . . . . . . . . local    REAL*4               4    006e
CCMAX . . . . . . . . . . . . local    REAL*4               4    0072
RESP. . . . . . . . . . . . . local    CHAR*1               1    0076
STEP. . . . . . . . . . . . . local    INTEGER*4            4    0078
D1H . . . . . . . . . . . . . local    REAL*4               4    007c
D2H . . . . . . . . . . . . . local    REAL*4               4    0080
D3H . . . . . . . . . . . . . local    REAL*4               4    0084
CHR . . . . . . . . . . . . . equiv    CHAR*1               6    000c
```

```
                        Microsoft FORTRAN Optimizing Compiler Version 4.00

Global Symbols

Name                     Class   Type              Size   Offset

DCALC . . . . . . . . . . extern  ***               ***     ***
FTUNE . . . . . . . . . . extern  ***               ***     ***
SGM . . . . . . . . . . . extern  ***               ***     ***
main. . . . . . . . . . . FSUBRT  ***               ***    0000

Code size = 03a8 (936)
Data size = 006b (107)
Bss size  = 0088 (136)

No errors detected
```

```
$storage:2
$declare
c       dcalc.for
c
c       a program to compute the D's for the EEG correction algorithm
c
c       October 12, 1989
c
c       Jeffrey C. Sigl

        subroutine dcalc(cls,d1v,d2v,d1h,d2h,d3v,d4v,d3h,d4h,step,bell,
     +ccmax)

c Data Structures

        character*1             cls(4)
        character*1             bell, resp
        integer                 i, j, n, zline, ezline, step, iresp
        integer                 step1
        real*4                  d1v, d2v, d1h, d2h
        real*4                  d3v, d4v, d3h, d4h, ccmax
        double precision z, h, phi, psi, pi2, capl, raddeg
        double precision betal, betar, gamal, gamar
        double precision theta, r, sigma, eta
        double precision betalv, betarv, gamalv, gamarv
        double precision thetav, rv, sigmav, etav
        double precision betalh, betarh, gamalh, gamarh
        double precision thetah, rh, sigmah, etah
        double precision denomv, denomh, temp, temp2, term1, term2
        double precision delta, jeff, negflag, max, scale

c Functions

        integer                 ichar
        double precision dacos, dsin, dcos, dsqrt, dabs


c Data Initialization

        pi2 = 1.5707963268D0
        raddeg = 57.2957795131D0

        n = 1
        z = 111.
        h = 70.
        capl = 8.
        betalv = 33.
        betarv = 94.
        betalh = 49.
        betarh = 144.
        zline = 0
        betal = 208.
        betar = 211.
        ccmax = 0.05
        ezline = 0

```

```
c Clear the screen

2       write(*,3)(cls(i),i=1,4)
3       format(' ',4a1)

c Write the Main Menu

        write(*,50)z,h,capl,betalv,betarv,betalh,betarh,zline,betal,
     +betar,ccmax
50      format(//20x,' GMS Engineering EEG-EOG Artifact Removal'//,
     +20x,'             Parameter Menu'////,
     +'  1',5x,'Distance between the eyes (mm).....................',
     +f9.2,/,
     +'  2',5x,'Distance from the origin to the stim electrode (mm)',
     +f9.2/,
     +'  3',5x,'Corneo-retinal distance (mm).......................',
     +f9.2,/,
     +'  4',5x,'Distance from Left Eye to VU-EOG electrode (mm)....',
     +f9.2,/,
     +'  5',5x,'Distance from Right Eye to VU-EOG electrode (mm)...',
     +f9.2,/,
     +'  6',5x,'Distance from Left Eye to H-EOG electrode (mm).....',
     +f9.2,/,
     +'  7',5x,'Distance from Right Eye to H-EOG electrode (mm)....',
     +f9.2,/,
     +'  8',5x,'H-EOG electrode above(0)/below(1) the "Z" line?.... ',
     +i5,/,
     +'  9',5x,'Distance from Left Eye to EEG electrode (mm).......',
     +f9.2,/,
     +' 10',5x,'Distance from Right Eye to EEG electrode (mm)......',
     +f9.2,/,
     +' 11',5x,'Maximum cross-correlation function for correction..',
     +f9.2,/,
     +' 12',5x,'Physical data entered; compute Correction Matrix'/,
     +/12x,' Enter Response    >'\)


c Read the response & take appropriate action

        read(*,'(i5)')iresp

        if (iresp .eq. 1) then
                write(*,110)
                read(*,'(f12.5)')z
                if ( z .lt. 0. ) then
                        z = 0.
                        call error(bell)
                endif

        elseif (iresp .eq. 2) then
                write(*,110)
                read(*,'(f12.5)')h
                if ( h .lt. 0. ) then
                        h = 0.
                        call error(bell)
                endif

        elseif (iresp .eq. 3) then
                write(*,110)
110             format(/13x,'Enter new value  >'\)
                read(*,'(f12.5)')capl
                if ( capl .lt. 0. ) then
                        capl = 8.
                        call error(bell)
                endif

        elseif (iresp .eq. 4) then
                write(*,110)
                read(*,'(f12.5)')betalv
                if ( betalv .lt. 0. ) then
                        betalv = 0.
                        call error(bell)
                endif

        elseif (iresp .eq. 5) then
                write(*,110)
                read(*,'(f12.5)')betarv
                if ( betarv .lt. 0. ) then
                        betarv = 0.
                        call error(bell)
                endif

        elseif (iresp .eq. 6) then
                write(*,110)
                read(*,'(f12.5)')betalh
                if ( betalh .lt. 0. ) then
                        betalh = 0.
                        call error(bell)
                endif

        elseif (iresp .eq. 7) then
                write(*,110)
                read(*,'(f12.5)')betarh
                if ( betarh .lt. 0. ) then
                        betarh = 0.
                        call error(bell)
                endif

        elseif (iresp .eq. 8) then
                write(*,110)
                read(*,'(i5)')zline
                if ( (zline .ne. 0) .and. (zline .ne. 1)) then
                        zline = 0
                        call error(bell)
                endif

        elseif (iresp .eq. 9) then
                write(*,110)
                read(*,'(f12.5)')betal
                if ( betal .lt. 0. ) then
                        betal = 0.
                        call error(bell)
                endif

        elseif (iresp .eq. 10) then
                write(*,110)
                read(*,'(f12.5)')betar
                if ( betar .lt. 0. ) then
                        betar = 0.
                        call error(bell)
                endif

        elseif (iresp .eq. 11) then
                write(*,110)
                read(*,'(f12.5)')ccmax
                if ( ccmax .lt. 0. ) then
                        ccmax = 0.
                        call error(bell)
                endif

        elseif (iresp .eq. 12) then
                if ((betal.eq.0.).or.(betar.eq.0.)) then
                        write(*,155)bell
155                     format(//,12x,'EEG electrode distances',
     +                  ' must be entered!'//,a1,12x,
     +                  'Type ENTER to continue...')
                        read(*,'(bn,a1)')resp
                        goto 2
                endif
                goto 98

        else
                call error(bell)

        endif

        goto 2


c Check if the VEOG electrode is below the stim electrode;
c       if so, negate the Dv's

98      delta = dacos( (z**2 - betalv**2 + betarv**2)
     #   / (2.*z*betarv) )
        if ( (betarv*dsin(delta)) .lt. h ) then
                negflag = -1.0D0
c               write(*,170)
c170            format(/' The EOGv electrode is below the STIM electrode.')
        else
                negflag = 1.0D0
c               write(*,172)
c172            format(' The EOGv electrode is above the STIM electrode.')
        endif

c Compute Vertical EOG parameters

c       write(*,23)
c23     format(/' EOGV')
```

```

        rv = dsqrt( 0.5 * ( betalv**2 + betarv**2 - ((z**2)/2.) ) )
c       write(*,200)rv
c200    format(' r ',f16.8)

        temp = (rv**2 + (z/2)**2 - betarv**2) / (rv * z)
        if ( temp .gt. 1. ) then
                temp = 1.0
        elseif ( temp .lt. -1. ) then
                temp = -1.0
        endif
        thetav = dacos( temp )
c       write(*,210)thetav*raddeg
c210    format(' theta ',f16.8,' degrees')

        gamalv = ( rv/betalv) * dsin( thetav )
c       write(*,230)gamalv
c230    format(' gamal ',f16.8)

        gamarv = ( rv/betarv) * dsin( thetav )
c       write(*,240)gamarv
c240    format(' gamar ',f16.8)

        sigmav = dsqrt( rv**2 + h**2 - 2.*rv*h*dsin(thetav) )
c       write(*,250)sigmav
c250    format(' sigma ',f16.8)

        etav = (-rv/sigmav) * dcos( thetav )
c       write(*,260)etav
c260    format(' eta ',f16.8)

c Compute Horizontal EOG parameters

c       write(*,24)
c24     format(/' EOGH')

        rh = dsqrt( 0.5 * ( betalh**2 + betarh**2 - ((z**2)/2.) ) )
c       write(*,200)rh

        temp = (rh**2 + (z/2)**2 - betarh**2) / (rh * z)
        if ( temp .gt. 1. ) then
                temp = 1.0
        elseif ( temp .lt. -1. ) then
                temp = -1.0
        endif
        thetah = dacos( temp )
        if ( zline .eq. 1 ) thetah = -thetah
c       write(*,210)thetah*raddeg

        gamalh = ( rh/betalh) * dsin( thetah )
c       write(*,230)gamalh

        gamarh = ( rh/betarh) * dsin( thetah )
c       write(*,240)gamarh

        sigmah = dsqrt( rh**2 + h**2 - 2.*rh*h*dsin(thetah) )
```

```
c     write(*,250)sigmah

      etah = (-rh/sigmah) * dcos( thetah )
c     write(*,260)etah


c Compute EEG electrode parameters

998   do 1000 i = 1, n

            r = dsqrt(0.5*(betal**2 + betar**2 - ((z**2)/2.)))
c           write(*,200)r

            temp = ( r**2 + (z/2)**2 - betar**2 ) / (r * z)
            if ( temp .gt. 1. ) then
                  temp = 1.0
            elseif ( temp .lt. -1. ) then
                  temp = -1.0
            endif
            theta = dacos( temp )
            if ( ezline .eq. 1 ) theta = -theta
c           write(*,210)theta*raddeg

            gamal = ( r/betal) * dsin( theta )
            gamar = ( r/betar) * dsin( theta )
c           write(*,230)gamal
c           write(*,240)gamar

            sigma = dsqrt( r**2 + h**2 - 2.*r*h*dsin(theta) )
            eta = (-r/sigma) * dcos( theta )
c           write(*,250)sigma
c           write(*,260)eta


c Compute the demoninators (V & H)

            psi = 0.
            temp = (sigma**(-2)) * ( -(dsqrt( 1.-(eta**2) )  ))
            temp2 = (sigmav**(-2)) * ( -(dsqrt( 1.-(etav**2) ) ) )
            denomv = temp / temp2

c           write(*,1212)denomv
c1212       format(' denomv = ',f16.8)

            psi = pi2
            temp = (sigma**(-2)) * eta
            temp2 = (sigmah**(-2)) * etah
            denomh = temp / temp2

c           write(*,1213)denomh
c1213       format(' denomh = ',f16.8)

c D1Vi
            phi = 0.
            term1 = (betal**(-2)) * gamal
            term2 = (betar**(-2)) * gamar
```

```
                d1v = 0.5 * negflag * ( term1 + term2 ) / denomv

c D1Hi
                phi = pi2
                term1 = (betal**(-2)) * (-dsqrt(1.-(gamal**2)))
                term2 = (betar**(-2)) * (dsqrt(1.-(gamar**2)))
                d1h = 0.5 * ( term1 + term2 ) / denomh

c D2Vi
                d2v = ( (1./betal) + (1./betar) ) / capl
                d2v = ( d2v / denomv )

c D2Hi
                d2h = ( (1./betal) + (1./betar) ) / capl
                d2h = d2h / denomh

1000    continue


c D3V
        phi = 0.
        term1 = (betalv**(-2)) * gamalv
        term2 = (betarv**(-2)) * gamarv
        d3v = 0.5 * ( term1 + term2 )

c D3H
        phi = pi2
        term1 = (betalh**(-2)) * (-dsqrt(1.-(gamalh**2)))
        term2 = (betarh**(-2)) * (dsqrt(1.-(gamarh**2)))
        d3h = 0.5 * ( term1 + term2 )

c D4V
        d4v = ( (1./betalv) + (1./betarv) ) / capl

c D4H
        d4h = ( (1./betalh) + (1./betarh) ) / capl


c Print out the data, as well as writing it to the ASCII file

c       write(*,2000)
c2000   format(///' The D"s are:',/)

c       write(*,2060)i, d1v, d1h, d2v, d2h
c2060   format(/' EEG Electrode # ',i3,/' D1V = ',f16.5,/
c     +' D1H = ',f16.5,/' D2V = ',f16.5,/' D2H = ',g16.5)

c       write(*,2010) d3v, d3h, d4v, d4h
c2010   format(/' D3V = ',f16.5,/' D3H = ',f16.5,
c     + /' D4V = ',f16.5,/' D4H = ',f16.5,//)

c Scale D's

        if ( dabs(d1v) .gt. 10. ) d1v = (d1v/dabs(d1v))*10.
        if ( dabs(d2v) .gt. 10. ) d2v = (d2v/dabs(d2v))*10.
        if ( dabs(d1h) .gt. 10. ) d1h = (d1h/dabs(d1h))*10.
```

```
 Line#  Source Line          Microsoft FORTRAN Optimizing Compiler Version 4.00

   393          if ( dabs(d2h) .gt. 10. ) d2h = (d2h/dabs(d2h))*10.
   394          if ( dabs(d3v) .gt. 10. ) d3v = (d3v/dabs(d3v))*10.
   395          if ( dabs(d4v) .gt. 10. ) d4v = (d4v/dabs(d4v))*10.
   396          if ( dabs(d3h) .gt. 10. ) d3h = (d3h/dabs(d3h))*10.
   397          if ( dabs(d4h) .gt. 10. ) d4h = (d4h/dabs(d4h))*10.
   398
   399          max = 0.0D0
   400          if ( dabs(d1v) .gt. max ) max = dabs(d1v)
   401          if ( dabs(d2v) .gt. max ) max = dabs(d2v)
   402          if ( dabs(d1h) .gt. max ) max = dabs(d1h)
   403          if ( dabs(d2h) .gt. max ) max = dabs(d2h)
   404          if ( dabs(d3v) .gt. max ) max = dabs(d3v)
   405          if ( dabs(d4v) .gt. max ) max = dabs(d4v)
   406          if ( dabs(d3h) .gt. max ) max = dabs(d3h)
   407          if ( dabs(d4h) .gt. max ) max = dabs(d4h)
   408
   409          scale = 8192.0D0 / max
   410          d1v = d1v * (-scale)
   411          d2v = d2v * (-scale)
   412          d3v = d3v * scale
   413          d4v = d4v * scale
   414          d1h = d1h * scale
   415          d2h = d2h * scale * 0.01
   416          d3h = d3h * scale
   417          d4h = d4h * scale
   418
   419  c       write(*,2100)
   420  c2100   format(///' The D"s for EEG.C96 are (in order):',/)
   421
   422  c       write(*,2070) scale*d1v, scale*d2v, scale*d3v,
   423  c      + scale*d4v, scale*d1h, scale*d2h, scale*d3h,
   424  c      + scale*d4h
   425  c2070   format(/8(' ',f9.0))
   426
   427          write(*,3333)
   428  3333    format(////////////'                          Please wait...'
   429       +              ////////////)
   430
   431          step = 3
   432
   433          return
   434          end


DCALC  Local Symbols

Name                        Class   Type            Size   Offset

CCMAX . . . . . . . . . . . param                           0006
BELL. . . . . . . . . . . . param                           000a
STEP. . . . . . . . . . . . param                           000e
D4H . . . . . . . . . . . . param                           0012
D3H . . . . . . . . . . . . param                           0016
D4V . . . . . . . . . . . . param                           001a
D3V . . . . . . . . . . . . param                           001e
D2H . . . . . . . . . . . . param                           0022
```

```
DCALC  Local Symbols

Name                         Class    Type              Size   Offset

D1H . . . . . . . . . . . . param                               0026
D2V . . . . . . . . . . . . param                               002a
D1V . . . . . . . . . . . . param                               002e
CLS . . . . . . . . . . . . param                               0032
ZLINE . . . . . . . . . . . local    INTEGER*2            2     0002
IRESP . . . . . . . . . . . local    INTEGER*2            2     0004
BETARV. . . . . . . . . . . local    REAL*8               8     0006
SIGMAV. . . . . . . . . . . local    REAL*8               8     000e
EZLINE. . . . . . . . . . . local    INTEGER*2            2     0016
H . . . . . . . . . . . . . local    REAL*8               8     0018
DENOMV. . . . . . . . . . . local    REAL*8               8     0020
I . . . . . . . . . . . . . local    INTEGER*2            2     0028
J . . . . . . . . . . . . . local    INTEGER*2            2     002a
PI2 . . . . . . . . . . . . local    REAL*8               8     002c
THETAV. . . . . . . . . . . local    REAL*8               8     0034
N . . . . . . . . . . . . . local    INTEGER*2            2     003c
R . . . . . . . . . . . . . local    REAL*8               8     003e
RH. . . . . . . . . . . . . local    REAL*8               8     0046
ETA . . . . . . . . . . . . local    REAL*8               8     004e
Z . . . . . . . . . . . . . local    REAL*8               8     0056
JEFF. . . . . . . . . . . . local    REAL*8               8     005e
CAPL. . . . . . . . . . . . local    REAL*8               8     0066
PHI . . . . . . . . . . . . local    REAL*8               8     006e
ETAH. . . . . . . . . . . . local    REAL*8               8     0076
GAMAL . . . . . . . . . . . local    REAL*8               8     007e
MAX . . . . . . . . . . . . local    REAL*8               8     0086
ICHAR . . . . . . . . . . . local    INTEGER*2            2     008e
RADDEG. . . . . . . . . . . local    REAL*8               8     0090
SCALE . . . . . . . . . . . local    REAL*8               8     0098
TEMP2 . . . . . . . . . . . local    REAL*8               8     00a0
RV. . . . . . . . . . . . . local    REAL*8               8     00a8
GAMAR . . . . . . . . . . . local    REAL*8               8     00b0
BETAL . . . . . . . . . . . local    REAL*8               8     00b8
TERM1 . . . . . . . . . . . local    REAL*8               8     00c0
DELTA . . . . . . . . . . . local    REAL*8               8     00c8
TERM2 . . . . . . . . . . . local    REAL*8               8     00d0
GAMALH. . . . . . . . . . . local    REAL*8               8     00d8
PSI . . . . . . . . . . . . local    REAL*8               8     00e0
NEGFLA. . . . . . . . . . . local    REAL*8               8     00e8
STEP1 . . . . . . . . . . . local    INTEGER*2            2     00f0
BETAR . . . . . . . . . . . local    REAL*8               8     00f2
GAMARH. . . . . . . . . . . local    REAL*8               8     00fa
BETALH. . . . . . . . . . . local    REAL*8               8     0102
ETAV. . . . . . . . . . . . local    REAL*8               8     010a
SIGMA . . . . . . . . . . . local    REAL*8               8     0112
TEMP. . . . . . . . . . . . local    REAL*8               8     011a
BETARH. . . . . . . . . . . local    REAL*8               8     0122
THETA . . . . . . . . . . . local    REAL*8               8     012a
GAMALV. . . . . . . . . . . local    REAL*8               8     0132
SIGMAH. . . . . . . . . . . local    REAL*8               8     013a
RESP. . . . . . . . . . . . local    CHAR*1               1     0142
```

```
DCALC  Local Symbols

Name                       Class   Type             Size   Offset

DENOMH. . . . . . . . . . . local   REAL*8              8    0144
THETAH. . . . . . . . . . . local   REAL*8              8    014c
GAMARV. . . . . . . . . . . local   REAL*8              8    0154
BETALV. . . . . . . . . . . local   REAL*8              8    015c


c -------------------------------------------------------------

        subroutine error(bell)

        character*1     resp, bell

        write(*,100)bell
 100    format(///12x,a1,'Invalid Response !'//,13x,
     +'Type ENTER to continue...')
        read(*,20)resp
 20     format(bn,a1)

        return
        end

ERROR  Local Symbols

Name                       Class   Type             Size   Offset

BELL. . . . . . . . . . . . param                            0006
RESP. . . . . . . . . . . . local   CHAR*1              1    0164

Global Symbols

Name                       Class   Type             Size   Offset

DCALC . . . . . . . . . . . FSUBRT  ***               ***    0000
ERROR . . . . . . . . . . . FSUBRT  ***               ***    1359

Code size = 1359 (4953)
Data size = 0206 (518)
Bss size  = 0165 (357)

No errors detected
```

```
$DECLARE
$LARGE

        subroutine sgm(magsum, orient)

c       Jeffrey C. Sigl         December 26, 1989


c Data Structures

        character*6     resp
        character*1     bite(2)
        character*1     cappa, cappb, cappc, cappd, cappe, cappf
        character*1     chr(6), one, sp, cr, retran, oktran
        integer*2       in, istart, i, j, k, irec, orient
        real*4          eeg(4096), magsum
        complex*8       sg(4096), sgtemp
        integer         tmprsp

c Functions

        integer         ichar
        real*4          float, cabs
        complex*8       cmplx

c Data Relations

        equivalence     (resp,chr)

        data cappa,cappb,cappc,cappd,cappe,cappf/'A','B','C','D','E','F'/
        data one /49/
        data sp, retran, oktran /8#140, 0, 1/

        open (9,file='scrtch.dat',status='new',access='sequential',
     +form='formatted')


c Load EEG data - Read 120 words

        j = 2018

        do 33 i = 1, 60

17              read(11,105)in
105             format(i6)

c               write(*,105)in

                orient = in - ((in/10) * 10)
                in = in/10
                if ( orient .eq. 1 ) then
                        in = -in
                endif

                eeg(j) = float(in)

                j=j+1

33      continue

c Extend ends

        do 20 i = 1, 2017
                eeg(i) = eeg(2018)
20      continue

        do 30 i = 2078, 4096
                eeg(i) = eeg(2077)
30      continue

c Window & FFT eeg

        call sgwin(eeg, eeg, 9, 0.001, 12)

        do 60 i = 1, 4096
                sg(i) = cmplx( eeg(i), 0. )
60      continue

        call cfft( sg, 12, 0, 1.0 )

        do 2323 i = 1, 4096
                write(9,*)sg(i)
2323    continue



c Load EOG data - Read 120 words

        j = 2018
        do 133 i = 1, 60

117             read(11,105)in

                orient = in - ((in/10) * 10)
                in = in/10
                if ( orient .eq. 1 ) then
                        in = -in
                endif

                eeg(j) = float(in)

                j=j+1
133     continue

c Extend ends

        do 120 i = 1, 2017
                eeg(i) = eeg(2018)
120     continue

        do 130 i = 2078, 4096
                eeg(i) = eeg(2077)
```

```
Line#  Source Line        Microsoft FORTRAN Optimizing Compiler Version 4.00

  113  130     continue
  114
  115  c Window & FFT eog
  116
  117          call sgwin(eeg, eeg, 9, 0.001, 12)
  118
  119          do 170 i = 1, 4096
  120                  sg(i) = cmplx( eeg(i), 0. )
  121  170     continue
  122
  123          call cfft( sg, 12, 0, 1.0 )
  124
  125
  126  c Divide & compute the average magnitude
  127
  128          magsum = 0.
  129          rewind 9
  130          do 1013 i = 6, 45
  131                  read(9,*)sgtemp
  132                  eeg(i) = 100. * cabs( sgtemp/sg(i) )
  133                  magsum = magsum + eeg(i)
  134
  135  c               write(*,2345)i,eeg(i),magsum
  136  c2345           format(' ',i6,2(' ',f15.3,))
  137
  138  1013    continue
  139          magsum = magsum / 40.
  140
  141  9999    clos´(9,status='delete')
  142
  143          return
  144          end


SGM  Local Symbols

Name                      Class   Type          Size   Offset

ORIENT. . . . . . . . . . param                         0006
MAGSUM. . . . . . . . . . param                         000a
EEG . . . . . . . . . . . local   REAL*4       16384    0000
I . . . . . . . . . . . . local   INTEGER*2        2    0002
J . . . . . . . . . . . . local   INTEGER*2        2    0004
K . . . . . . . . . . . . local   INTEGER*2        2    0006
SGTEMP. . . . . . . . . . local   COMPLEX*8        8    0008
CAPPA . . . . . . . . . . local   CHAR*1           1    000a
CAPPB . . . . . . . . . . local   CHAR*1           1    000b
CAPPC . . . . . . . . . . local   CHAR*1           1    000c
CAPPD . . . . . . . . . . local   CHAR*1           1    000d
CAPPE . . . . . . . . . . local   CHAR*1           1    000e
CAPPF . . . . . . . . . . local   CHAR*1           1    000f
ONE . . . . . . . . . . . local   CHAR*1           1    0010
CR. . . . . . . . . . . . local   CHAR*1           1    0010
SP. . . . . . . . . . . . local   CHAR*1           1    0011
RETRAN. . . . . . . . . . local   CHAR*1           1    0012
ISTART. . . . . . . . . . local   INTEGER*2        2    0012
```

```
                                      Microsoft FORTRAN Optimizing Compiler Version 4.00


SGM  Local Symbols

Name                       Class    Type             Size    Offset

OKTRAN. . . . . . . . . . . local   CHAR*1              1     0013
IN. . . . . . . . . . . . . local   INTEGER*2           2     0014
IREC. . . . . . . . . . . . local   INTEGER*2           2     0016
TMPRSP. . . . . . . . . . . local   INTEGER*4           4     0018
ICHAR . . . . . . . . . . . local   INTEGER*4           4     001c
RESP. . . . . . . . . . . . local   CHAR*6              6     0020
SG. . . . . . . . . . . . . local   COMPLEX*8       32768     4000
BITE. . . . . . . . . . . . local   CHAR*1              2     c000
CHR . . . . . . . . . . . . local   CHAR*1              6     0020


Global Symbols

Name                       Class    Type             Size    Offset

CFFT. . . . . . . . . . . . extern  ***               ***      ***
SGM . . . . . . . . . . . . FSUBRT  ***               ***     0000
SGWIN . . . . . . . . . . . extern  ***               ***      ***

Code size = 04b0 (1200)
Data size = 0060 (96)
Bss size  = 0026 (38)

No errors detected
```

FTUNE2

```
$LARGE
$declare
c      ftune.for
c
c      Steven M. Falk

       subroutine ftune(d1v,d2v,d1h,d2h,d3v,d4v,d3h,d4h,vmag,hmag,gain,
     +ccmax)

c Data Structures

       character*1      cls(4), chr(6), cbell
       character*1      resp, sp, retran, oktran, cr
       integer          i, j, n, k, l, tmprsp, in, mod
       real*4           d1v, d2v, d1h, d2h
       real*4           d3v, d4v, d3h, d4h, ccmax
       real*4           cc, ccrawv, ccrawh, ccold, delta1, delta2, ccrtio
       integer          ichar
       real*4           float, cabs, real, abs
       complex*8        cmplx
       character        yes, yess
       integer*2        num, iorder, icnst2, ilim, orent,orient
       real*4           eogvu(512), eogvl(512), eogh(512), raweeg(512)
       real*4           eohvu(512), eohvl(512), eohh(512), raweeh(512)
       real*4           alpha(512), temp(512)
       real*4           time, alpha1, alpha2, const, intrvl, ceeg
       real*4           vmag, hmag, gain, raddeg, order, const1, pi2
       complex*8        comp1(512), comp2(512)
       double precision scale, max, dabs

       equivalence      (resp,chr)

c Data Initialization

       pi2 = 1.57079632680D0
       raddeg = 57.2957795131D0
       data     yes, yess /'y','Y'/
       data sp, retran, oktran /8#140, 0, 1/
       data cbell / 8#7/

c      delta1 = 0.5 * d1v
       delta1 = 100.
       delta2 = 0.5 * d2v
       do 401 i = 1, 512

407             read(11,402)in
402             format(i6)

                orent = in - ((in/10) * 10)
                in = in/10
                if ( orent .eq. 1 ) then
                        in = -in
                endif


c               if (abs(float(in)) .gt. 470.) then
```

```
c                         gain = -9999.
c                         write (*,4433)
c4433                     format(' Data is saturated.  Interrogate again.')
c                         goto 2222
c                 endif

                  raweeg(i) = float(in)

401       continue

          do 1401 i = 1, 512

1407              read(11,1402)in
1402              format(i6)

                  orent = in - ((in/10) * 10)
                  in = in/10
                  if ( orent .eq. 1 ) then
                          in = -in
                  endif

c                 if (abs(float(in)) .gt. 470.) then
c                         gain = -9999.
c                         write (*,4433)
c                         goto 2222
c                 endif

                  raweeg(i) = float(in)

1401      continue

          do 411 i = 1, 512

417               read(11,412)in
412               format(i6)

                  orent = in - ((in/10) * 10)
                  in = in/10
                  if ( orent .eq. 1 ) then
                          in = -in
                  endif

c                 if (abs(float(in)) .gt. 470.) then
c                         gain = -9999.
c                         write (*,4433)
c                         goto 2222
c                 endif

                  eogh(i) = float(in)

411       continue

          do 1411 i = 1, 512

1417              read(11,1412)in
1412              format(i6)
```

```

                orent = in - ((in/10) * 10)
                in = in/10
                if ( orent .eq. 1 ) then
                        in = -in
                endif

c               if (abs(float(in)) .gt. 470.) then
c                       gain = -9999.
c                       write (*,4433)
c                       goto 2222
c               endif

                eogh(i) = float(in)

1411    continue

        do 421 i = 1, 512

427             read(11,422)in
422             format(i6)

                orent = in - ((in/10) * 10)
                in = in/10
                if ( orent .eq. 1 ) then
                        in = -in
                endif

c               if (abs(float(in)) .gt. 470.) then
c                       gain = -9999.
c                       write (*,4433)
c                       goto 2222
c               endif

                eogvu(i) = float(in)

421     continue

        do 1421 i = 1, 512

1427            read(11,1422)in
1422            format(i6)

                orent = in - ((in/10) * 10)
                in = in/10
                if ( orent .eq. 1 ) then
                        in = -in
                endif

c               if (abs(float(in)) .gt. 470.) then
c                       gain = -9999.
c                       write (*,4433)
c                       goto 2222
c               endif

                eogvu(i) = float(in)
```

```

1421    continue

        do 431 i = 1, 512

437             read(11,432)in
432             format(i6)

                orent = in - ((in/10) * 10)
                in = in/10
                if ( orent .eq. 1 ) then
                        in = -in
                endif

c               if (abs(float(in)) .gt. 470.) then
c                       gain = -9999.
c                       write (*,4433)
c                       goto 2222
c               endif

                eogvl(i) = float(in)

431     continue

        do 1431 i = 1, 512

1437            read(11,1432)in
1432            format(i6)

                orent = in - ((in/10) * 10)
                in = in/10
                if ( orent .eq. 1 ) then
                        in = -in
                endif

c               if (abs(float(in)) .gt. 470.) then
c                       gain = -9999.
c                       write (*,4433)
c                       goto 2222
c               endif

                eogvl(i) = float(in)

1431    continue


c               fine tuning algorithm

11      continue

        call ccf(eogvu,raweeg,ccrawv)
        call ccf(eogh,raweeg,ccrawh)

        call crct(d1v,d2v,d1h,d2h,d3v,d4v,d3h,d4h,vmag,hmag,gain,
     +eogvu,eogvl,eogh,raweeg,temp)

```

```
      call ccf(eogvu,temp,ccold)

      if (abs(ccold) .gt. abs(ccrawv)) then
              write(*,1109)cbell
1109          format(' Data Entry Error!',a1)
              gain = -9999.
              goto 2222
      endif

      if (abs(ccold) .gt. 0.8) then
              write(*,1108)cbell
1108          format(' Measurement Error!',a1)
              gain = -9999.
              goto 2222
      endif

      call ccf(eogh,temp,ccold)

      if (abs(ccold) .gt. abs(ccrawh)) then
              write(*,1109)cbell
              gain = -9999.
              goto 2222
      endif

      if (abs(ccold) .gt. 0.8) then
              write(*,1108)cbell
              gain = -9999.
              goto 2222
      endif

2431  write(*,2460)
2460  format(' Fine tuning geometric VERTICAL parameters of model...')
      write(*,2462)
2462  format('     Iteration       D1            D2              CCF')

      call ccf(eogvu,temp,ccold)

      l = 0
      write(*,*)l,d1v,d2v,ccold
2500  l = l + 1

      d1v = d1v + delta1
      call crct(d1v,d2v,d1h,d2h,d3v,d4v,d3h,d4h,vmag,hmag,gain,
     +eogvu,eogvl,eogh,raweeg,temp)
      call ccf(eogvu,temp,cc)

      ccrtio = cc / ccold
      if (ccrtio .lt. 0) then
              delta1 = delta1 * (-.5)
              goto 2501
      endif

      if (abs(cc) .gt. abs(ccold)) then
              delta1 = delta1 * (-1.)
              goto 2501
      endif
```

```

2501     ccold = cc
         d2v = d2v + delta2
         call crct(d1v,d2v,d1h,d2h,d3v,d4v,d3h,d4h,vmag,hmag,gain,
     +eogvu,eogvl,eogh,raweeg,temp)
         call ccf(eogvu,temp,cc)

         ccrtio = cc / ccold
         if (ccrtio .lt. 0) then
                 delta2 = delta2 * (-.5)
                 goto 2511
         endif

         if (abs(cc) .gt. abs(ccold)) then
                 delta2 = delta2 * (-1.)
                 goto 2511
         endif

2511     write(*,*)l,d1v,d2v,cc
         j = mod(l,10)
         if (j .eq. 0) then
                 write(*,2512)
2512             format(' Continue iterations ? (Y/N) ',\)
                 read(*,2513)resp
2513             format(a1)
                 if (resp .ne. 'Y') then
                         write(*,2518)
2518                     format( ' Fine tuning geometric HORIZONTAL parameters',
     +' of model...')
                         write(*,2462)
                         call ccf(eogh,temp,ccold)
                         l=0
                         write(*,*)l,d1h,d2h,ccold
                         delta1 = 0.5 * d1h
                         delta2 = 0.5 * d2h
                         goto 2600
                 endif
         endif
         ccold = cc
         if (abs(cc) .lt. ccmax) then
                 write(*,2518)
                 write(*,2462)
                 call ccf(eogh,temp,ccold)
                 l=0
                 write(*,*)l,d1h,d2h,ccold
                 delta1 = 0.5 * d1h
                 delta2 = 0.5 * d2h
                 goto 2600

         endif
         goto 2500

2600     l = l + 1

         d1h = d1h + delta1
         call crct(d1v,d2v,d1h,d2h,d3v,d4v,d3h,d4h,vmag,hmag,gain,
     +eogvu,eogvl,eogh,raweeg,temp)
        call ccf(eogh,temp,cc)

        ccrtio = cc / ccold
        if (ccrtio .lt. 0) then
                delta1 = delta1 * (-.5)
                goto 2601
        endif

        if (abs(cc) .gt. abs(ccold)) then
                delta1 = delta1 * (-1.)
                goto 2601
        endif

2601    ccold = cc
        d2h = d2h + delta2
        call crct(d1v,d2v,d1h,d2h,d3v,d4v,d3h,d4h,vmag,hmag,gain,
     +eogvu,eogvl,eogh,raweeg,temp)
        call ccf(eogh,temp,cc)

        ccrtio = cc / ccold
        if (ccrtio .lt. 0) then
                delta2 = delta2 * (-.5)
                goto 2611
        endif

        if (abs(cc) .gt. abs(ccold)) then
                delta2 = delta2 * (-1.)
                goto 2611
        endif

2611    write(*,*)l,d1h,d2h,cc
        j = mod(l,10)
        if (j .eq. 0) then
                write(*,2512)
                read(*,2513)resp
                if (resp .ne. 'Y') then
                        goto 2800
                endif
        endif
        ccold = cc
        if (abs(cc) .lt. ccmax) then
                goto 2800
        endif
        goto 2600

2800    continue

        open(12,file='correeg.dat')
        do 2803 i=64,384
                write(12,*)i,temp(i),raweeg(i),eogvu(i),eogh(i)
2803    continue
        close(12)

c Scale D's

```

```
Line#  Source Line          Microsoft FORTRAN Optimizing Compiler Version 4.00

  393            max = 0.0D0
  394            if ( dabs(d1v) .gt. max ) max = dabs(d1v)
  395            if ( dabs(d2v) .gt. max ) max = dabs(d2v)
  396            if ( dabs(d1h) .gt. max ) max = dabs(d1h)
  397            if ( dabs(d2h) .gt. max ) max = dabs(d2h)
  398            if ( dabs(d3v) .gt. max ) max = dabs(d3v)
  399            if ( dabs(d4v) .gt. max ) max = dabs(d4v)
  400            if ( dabs(d3h) .gt. max ) max = dabs(d3h)
  401            if ( dabs(d4h) .gt. max ) max = dabs(d4h)
  402
  403            scale = 8192.0D0 / max
  404            d1v = d1v * scale
  405            d2v = d2v * scale
  406            d3v = d3v * scale
  407            d4v = d4v * scale
  408            d1h = d1h * scale
  409            d2h = d2h * scale
  410            d3h = d3h * scale
  411            d4h = d4h * scale
  412
  413  2222      return
  414            end
```

```
FTUNE  Local Symbols

Name                        Class   Type              Size   Offset

CCMAX . . . . . . . . . . . param                             0006
GAIN. . . . . . . . . . . . param                             000a
HMAG. . . . . . . . . . . . param                             000e
VMAG. . . . . . . . . . . . param                             0012
D4H . . . . . . . . . . . . param                             0016
D3H . . . . . . . . . . . . param                             001a
D4V . . . . . . . . . . . . param                             001e
D3V . . . . . . . . . . . . param                             0022
D2H . . . . . . . . . . . . param                             0026
D1H . . . . . . . . . . . . param                             002a
D2V . . . . . . . . . . . . param                             002e
D1V . . . . . . . . . . . . param                             0032
EOGVU . . . . . . . . . . . local   REAL*4            2048    0000
CMPLX . . . . . . . . . . . local   COMPLEX*8            8    0002
CCRTIO. . . . . . . . . . . local   REAL*4               4    000a
YES . . . . . . . . . . . . local   CHAR*1               1    000d
YESS. . . . . . . . . . . . local   CHAR*1               1    000e
IORDER. . . . . . . . . . . local   INTEGER*2            2    000e
SP. . . . . . . . . . . . . local   CHAR*1               1    000f
RETRAN. . . . . . . . . . . local   CHAR*1               1    0010
CCRAWV. . . . . . . . . . . local   REAL*4               4    0010
OKTRAN. . . . . . . . . . . local   CHAR*1               1    0011
CBELL . . . . . . . . . . . local   CHAR*1               1    0012
CC. . . . . . . . . . . . . local   REAL*4               4    0014
CONST . . . . . . . . . . . local   REAL*4               4    0018
ORENT . . . . . . . . . . . local   INTEGER*2            2    001c
I . . . . . . . . . . . . . local   INTEGER*4            4    001e
J . . . . . . . . . . . . . local   INTEGER*4            4    0022
```

```
FTUNE  Local Symbols

Name                        Class  Type            Size  Offset

PI2 . . . . . . . . . . . . local  REAL*4             4   0026
K . . . . . . . . . . . . . local  INTEGER*4          4   002a
L . . . . . . . . . . . . . local  INTEGER*4          4   002e
N . . . . . . . . . . . . . local  INTEGER*4          4   0032
ORIENT. . . . . . . . . . . local  INTEGER*2          2   0036
CEEG. . . . . . . . . . . . local  REAL*4             4   0038
CR. . . . . . . . . . . . . local  CHAR*1             1   003c
ALPHA1. . . . . . . . . . . local  REAL*4             4   003e
IN. . . . . . . . . . . . . local  INTEGER*4          4   0042
ALPHA2. . . . . . . . . . . local  REAL*4             4   0046
CABS. . . . . . . . . . . . local  REAL*4             4   004a
DELTA1. . . . . . . . . . . local  REAL*4             4   004e
DELTA2. . . . . . . . . . . local  REAL*4             4   0052
INTRVL. . . . . . . . . . . local  REAL*4             4   0056
REAL. . . . . . . . . . . . local  REAL*4             4   005a
CCOLD . . . . . . . . . . . local  REAL*4             4   005e
MAX . . . . . . . . . . . . local  REAL*8             8   0062
TMPRSP. . . . . . . . . . . local  INTEGER*4          4   006a
RADDEG. . . . . . . . . . . local  REAL*4             4   006e
ICHAR . . . . . . . . . . . local  INTEGER*4          4   0072
SCALE . . . . . . . . . . . local  REAL*8             8   0076
ILIM. . . . . . . . . . . . local  INTEGER*2          2   007e
TIME. . . . . . . . . . . . local  REAL*4             4   0080
NUM . . . . . . . . . . . . local  INTEGER*2          2   0084
ICNST2. . . . . . . . . . . local  INTEGER*2          2   0086
CONST1. . . . . . . . . . . local  REAL*4             4   0088
CCRAWH. . . . . . . . . . . local  REAL*4             4   008c
ORDER . . . . . . . . . . . local  REAL*4             4   0090
EOHVU . . . . . . . . . . . local  REAL*4          2048   0800
CHR . . . . . . . . . . . . local  CHAR*1             6   1000
COMP1 . . . . . . . . . . . local  COMPLEX*8       4096   1006
COMP2 . . . . . . . . . . . local  COMPLEX*8       4096   2006
CLS . . . . . . . . . . . . local  CHAR*1             4   3006
EOGH. . . . . . . . . . . . local  REAL*4          2048   300a
EOHH. . . . . . . . . . . . local  REAL*4          2048   380a
ALPHA . . . . . . . . . . . local  REAL*4          2048   400a
TEMP. . . . . . . . . . . . local  REAL*4          2048   480a
RAWEEG. . . . . . . . . . . local  REAL*4          2048   500a
RAWEEH. . . . . . . . . . . local  REAL*4          2048   580a
EOGVL . . . . . . . . . . . local  REAL*4          2048   600a
EOHVL . . . . . . . . . . . local  REAL*4          2048   680a
RESP. . . . . . . . . . . . equiv  CHAR*1             1   1000
```

```

c -----------------------------------------------------------------

        subroutine ccf(ueeg,ceeg,cc)

        real*4          cc,cov,sho
        real*4          ueeg(512),ceeg(512)
        real*8          a(512,6),b(6)
        integer*2       ii,jj


        do 10 ii=1,512
                a(ii,1) = ueeg(ii)
                a(ii,2) = ceeg(ii)
                a(ii,3) = a(ii,1)*a(ii,2)
                a(ii,4) = a(ii,1)+a(ii,2)
                a(ii,5) = a(ii,1)*a(ii,1)
                a(ii,6) = a(ii,2)*a(ii,2)
 10     continue

        do 20 ii=1,6
                b(ii) = 0.0
 20     continue

        do 30 ii=64,448
                do 31 jj=1,6
                        b(jj) = b(jj) + a(ii,jj)
 31             continue
 30     continue
        do 40 ii=1,6
                b(ii) = b(ii) / 384.0
 40     continue

        cov = b(3) - (b(1) * b(2))
        sho = (b(5)-(b(1)*b(1))) * (b(6)-(b(2)*b(2)))
        if ( sho .le. 0.0 ) then
                sho = 0.0
        endif
        sho = sho**.5
        if ( sho .eq. 0.0 ) then
                cc = 1.0
                goto 75
        endif
        cc = cov / sho

 75     continue

        return
        end
```

```
CCF  Local Symbols

Name                          Class   Type              Size   Offset

CC. . . . . . . . . . . . . . param                             0006
CEEG. . . . . . . . . . . . . param                             000a
UEEG. . . . . . . . . . . . . param                             000e
II. . . . . . . . . . . . . . local   INTEGER*2            2    0094
JJ. . . . . . . . . . . . . . local   INTEGER*2            2    0096
COV . . . . . . . . . . . . . local   REAL*4               4    0098
SHO . . . . . . . . . . . . . local   REAL*4               4    009c
A . . . . . . . . . . . . . . local   REAL*8           24576    7142
B . . . . . . . . . . . . . . local   REAL*8              48    d142
```

```


c-------------------------------------------------

      subroutine crct(d1v,d2v,d1h,d2h,d3v,d4v,d3h,d4h,vmag,hmag,gain,
     +eogvu,eogvl,eogh,raweeg,temp)

      integer        i, j, n, k, tmprsp, in
      real*4         d1v, d2v, d1h, d2h
      real*4         d3v, d4v, d3h, d4h
      real*4         float, cabs, real
      complex*8      cmplx
      real*4         eogvu(512), eogvl(512), eogh(512), raweeg(512)
      real*4         teogvu(52), teogvl(512), teogh(512)
      real*4         alpha(512), temp(512)
      real*4         time, alpha1, alpha2, const, intrvl, ceeg
      real*4         vmag, hmag, gain, raddeg, order, const1, pi2
      complex*8      comp1(512), comp2(512)


c Window & FFT EOG-VU

      call sgwin(eogvu, teogvu, 9, 0.001, 9)
      do 60 i = 1, 512
            comp1(i) = cmplx( teogvu(i), 0. )
60    continue
      call cfft( comp1, 9, 0, 1.0 )


c Window & FFT EOG-VL

      call sgwin(eogvl, teogvl, 9, 0.001, 9)
      do 70 i = 1, 512
            comp2(i) = cmplx( teogvl(i), 0. )
70    continue
      call cfft( comp2, 9, 0, 1.0 )


c Compute Alpha

      do 80 i = 1, 512
            temp(i) = (gain * cabs( comp1(i) / comp2(i) )) / 100.

            if (temp(i) .lt. 1.) then
                  temp(i) = 1.
            elseif (temp(i) .gt. 4.) then
                  temp(i) = 4.
            endif

            alpha(i) = temp(i)
80    continue

      goto 8989

c Moving Average Filter of Alpha (7 point)
```

```

      alpha(1) = ((4.*temp(1)) + temp(2) + temp(3) + temp(4)) / 7.
      alpha(2) = ((3.*temp(1)) + temp(2) + temp(3) + temp(4)
     +           + temp(5)) / 7.
      alpha(3) = ((2.*temp(1)) + temp(2) + temp(3) + temp(4)
     +           + temp(5) + temp(6)) / 7.
      do 90 i = 4, 509
              alpha(i) = (temp(i-3) + temp(i-2) + temp(i-1) + temp(i) +
     +                    temp(i+1) + temp(i+2) + temp(i+3)) / 7.
90    continue
      alpha(510) = (temp(507) + temp(508) + temp(509) +
     +       temp(510) + temp(511) + (2.*temp(512))) / 7.
      alpha(511) = (temp(508) + temp(509) + temp(510) +
     +                 temp(511) + (3.*temp(512))) / 7.
      alpha(512) = (temp(509) + temp(510) + temp(511) +
     +                (4.*temp(512))) / 7.


c Window & FFT EOG-H

8989  call sgwin(eogh, teogh, 9, 0.001, 9)
      do 100 i = 1, 512
              comp2(i) = cmplx( teogh(i), 0. )
100   continue
      call cfft( comp2, 9, 0, 1.0 )


c ======================================================
c                        Correction
c ======================================================

      do 1000 i = 1, 512

              alpha1 = alpha(i) + 1.
              alpha2 = alpha(i) - 1.

c Vertical Component

              const = (d1v*alpha1 + d2v*alpha2) / (d3v*alpha1 + d4v*alpha2)
              comp1(i) = const * vmag * comp1(i) / 100.

c Horizontal Component

              const = (d1h*alpha1 + d2h*alpha2) / (d3h*alpha1 + d4h*alpha2)
              comp1(i) = comp1(i) + (const * hmag * comp2(i)) / 100.

              temp(i) = 1.

1000  continue


c Inverse Transform

      call cift( comp1, 9, 0, 1.0 )


```

```
Line# Source Line        Microsoft FORTRAN Optimizing Compiler Version 4.00

  575 c Dewindow Corrector & Subtract from Raw EEG
  576
  577         call sgwin(temp, temp, 9, 0.001, 9)
  578         do 1100 i = 1, 512
  579                 temp(i) = real(compl(i)) / temp(i)
  580                 temp(i) = raweeg(i) - temp(i)
  581
  582 1100    continue
  583
  584         return
  585         end

CRCT  Local Symbols

Name                        Class    Type            Size   Offset

TEMP. . . . . . . . . . . . param                           0006
RAWEEG. . . . . . . . . . . param                           000a
EOGH. . . . . . . . . . . . param                           000e
EOGVL . . . . . . . . . . . param                           0012
EOGVU . . . . . . . . . . . param                           0016
GAIN. . . . . . . . . . . . param                           001a
HMAG. . . . . . . . . . . . param                           001e
VMAG. . . . . . . . . . . . param                           0022
D4H . . . . . . . . . . . . param                           0026
D3H . . . . . . . . . . . . param                           002a
D4V . . . . . . . . . . . . param                           002e
D3V . . . . . . . . . . . . param                           0032
D2H . . . . . . . . . . . . param                           0036
D1H . . . . . . . . . . . . param                           003a
D2V . . . . . . . . . . . . param                           003e
D1V . . . . . . . . . . . . param                           0042
ALPHA . . . . . . . . . . . local    REAL*4          2048   0000
CONST . . . . . . . . . . . local    REAL*4             4   00a0
I . . . . . . . . . . . . . local    INTEGER*4          4   00a4
J . . . . . . . . . . . . . local    INTEGER*4          4   00a8
PI2 . . . . . . . . . . . . local    REAL*4             4   00ac
K . . . . . . . . . . . . . local    INTEGER*4          4   00b0
N . . . . . . . . . . . . . local    INTEGER*4          4   00b4
CEEG. . . . . . . . . . . . local    REAL*4             4   00b8
ALPHA1. . . . . . . . . . . local    REAL*4             4   00bc
IN. . . . . . . . . . . . . local    INTEGER*4          4   00c0
ALPHA2. . . . . . . . . . . local    REAL*4             4   00c4
INTRVL. . . . . . . . . . . local    REAL*4             4   00c8
TMPRSP. . . . . . . . . . . local    INTEGER*4          4   00cc
RADDEG. . . . . . . . . . . local    REAL*4             4   00d0
TIME. . . . . . . . . . . . local    REAL*4             4   00d4
FLOAT . . . . . . . . . . . local    REAL*4             4   00d8
CONST1. . . . . . . . . . . local    REAL*4             4   00dc
ORDER . . . . . . . . . . . local    REAL*4             4   00e0
TEOGH . . . . . . . . . . . local    REAL*4          2048   0800
TEOGVL. . . . . . . . . . . local    REAL*4          2048   d172
TEOGVU. . . . . . . . . . . local    REAL*4           208   d972
COMP1 . . . . . . . . . . . local    COMPLEX*8       4096   da42
COMP2 . . . . . . . . . . . local    COMPLEX*8       4096   ea42
```

```
Global Symbols

Name                       Class   Type              Size   Offset

CCF . . . . . . . . . . . . FSUBRT ***                ***    11f2
CFFT. . . . . . . . . . . . extern ***                ***     ***
CIFT. . . . . . . . . . . . extern ***                ***     ***
CRCT. . . . . . . . . . . . FSUBRT ***                ***    1590
FTUNE . . . . . . . . . . . FSUBRT ***                ***    0000
SGWIN . . . . . . . . . . . extern ***                ***     ***

Code size = 2282 (8834)
Data size = 01b3 (435)
Bss size  = 00e4 (228)

No errors detected
```